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FULL-SCALE EVALUATION OF ACTIVATED BIO-FILTER WASTEWATER TREATMENT PROCESS

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16. ABSTRACT

The City of Helena, Montana uses an activated bio-filter (ABF) process for secondary treatment of its wastewater. The biological process consists of a redwood tower (bio-cell) and a short-term aeration unit. The ABF process is relatively new, and full-scale performance information at design loadings was not available. The primary objective of this research effort was to develop process operation and performance information at loadings near the manufacturer's recommended design criteria during the winter months of the year. Other objectives were to determine system energy requirements and system sludge production values.

Three process loadings were evaluated during a 17-mo time frame. Period A was 12 wk in length with the full bio-cell and aeration basin facilities in service, resulting in loadings of about 40 percent of the manufacturer's recommended design values. Period B was 20 wk in length with half of the bio- cell removed from service. Period C was 23 wk in length with half of the bio-cell and half of the aeration basin removed from service. After formal project data collection, the nominal Period B loading conditions were retested during a 16-wk run called Period B'. Optimum process control was developed during Periods A and B and was fully exercised during Periods C and B', allowing system design capabilities to be fully evaluated. Also, the evaluation was conducted without the potential negative impact of sludge treatment recycle streams back through the treatment process.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater solids and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communication link between the researcher and the user community.

As part of these activities, this report describes the first full-scale evaluation of the activated bio-filter (ABF) process designed to achieve year-round secondary treatment of municipal wastewater. The results and recommendations documented herein should be of particular interest to design engineers and municipal officials charged with cost-effective biological process selection for new and retrofit treatment plant expansion. Operators of ABF systems should also benefit from a thorough review of this report.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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ABSTRACT

The City of Helena, Montana, uses an activated bio-filter (ABF)* process for secondary treatment of its wastewater. The biological process consists of a redwood tower (bio-cell) and a short-term aeration unit. The ABF process is relatively new, and full-scale performance information at design loading was not available. The primary objective of this research effort was to develop process operation and performance information at loadings near the manufacturer's recommended design criteria during the winter months of the year. Other objectives were to determine system energy requirements and system sludge production values.

Three process loadings were evaluated. Period A had the full bio-cell and aeration basin facilities in service, resulting in loadings of about 40 percent of the manufacturer's recommended design values. In Period B, half of the bio-cell was removed from service. In Period C, half of the aeration basin was also removed from service. After formal project data collection, the nominal Period B loading conditions were retested. Optimum process control was developed, allowing system design capabilities to be fully evaluated without the potential negative impact of sludge treatment recycle streams back through the treatment process.

All secondary treatment standards were met during Periods A and B'. The monthly average total suspended solids (TSS) standard of 30 mg/l was violated during one 5-wk stretch of Period B due to operational procedures. Period C loadings were about 75 percent of design. All standards were met during Period C, except the 85 percent BOD_5 removal requirement during a 10-wk stretch when influent raw wastewater BOD_5 concentrations were unusually low. Overall process energy requirements for all three periods were less than theoretically determined for a similar-sized conventional activated sludge plant, with the potential for even greater savings with various design modifications. Total sludge production data indicated that sludge treatment and disposal facilities should be sized to handle an average of 1.1 kg TSS/kg BOD_5 removed, and should be capable of handling significantly higher production values for several months at a time.

This report was submitted in fulfillment of Grant No. R806047 by the City of Helena, Montana, under the partial sponsorship of the U.S. Environmental Protection Agency. The report covers the period December 1, 1979, to July 10, 1980, and work was completed as of January 15, 1982.

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*A trade name employed by the proprietor of the process, Neptune Microfloc, Inc.

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SECTION 1

INTRODUCTION

GENERAL

Biological wastewater treatment processes are generally classified as either suspended growth, i.e., activated sludge, or attached growth, i.e., trickling filters. A modification of these two classifications has been developed called the activated bio-filter (ABF). The ABF process is marketed by Neptune Microfloc, Inc. for use in secondary treatment and nitrification applications. The subject of this research effort is the ABF process used as a secondary treatment process.

The ABF process consists of a bio-cell and a short-term aeration unit. The bio-cell is comprised of redwood media stacked in a tower, over which primary effluent is distributed. In addition to the attached growth properties of this system, sludge from the secondary clarifiers is recycled to mix with the primary effluent, resulting in a mixed liquor that is distributed over the redwood tower. Originally the bio-cell unit with "mixed liquor" distribution was the only biological unit of the ABF process. Later, a modification was incorporated that provided for short-term aeration of the mixed liquor after the bio-cell and before clarification.

Many ABF systems are being considered for new plant design and existing plant upgrades throughout the United States. However, limited full-scale performance information is available for the process at design loading conditions. Neptune Microfloc's current design recommendations for the bio-cell and short-term aeration unit sizes are based primarily upon pilot plant operating results, coupled with process theory considerations. The potential use of ABF systems as a secondary treatment alternative makes cost and performance data from a full-scale ABF treatment process a subject of major interest.

HELENA ABF PROCESS

Helena is the capital of Montana and is located in the west-central part of the state on the east slope of the continental divide. The elevation is 1,160 m (3,800 ft) above sea level. Air temperatures range from -34°C in the winter to 38°C in the summer. The average annual temperature is 6°C. Precipitation averages 29 cm (11.4 in.) per yr. The City utilizes the ABF process for secondary treatment. This facility was well suited for a comprehensive performance assessment because it was possible to operate the system at different loading conditions, including near design loadings using existing wastewater flow rates. Also, Helena experiences extreme ambient temperature variations that allowed the ABF system to be evaluated over a changing

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temperature range. Additionally, recycle of sludge treatment sidestreams is not practiced at Helena, allowing an evaluation of the ABF process to be made without this potential for interference in data acquisition and interpretation.

The Helena plant serves the population within the City limits plus several adjacent areas. The estimated service population is 28,000, with no major industrial contributors. The treatment facilities are designed for an average daily flow of 22,700 m^3/day (6.0 mgd). The annual average raw wastewater flow rates and BOD_5 and TSS concentrations for 1977, 1978, and 1979 are shown in Table 1. The plant was operating at about half design flow capacity during this period.

It is estimated that about 10-15 percent of the current wastewater flow is from groundwater infiltration. Also, some roof drains and surface water drains are connected to the City collection system and contribute to peak flows during snow melt and rains. Short-term peak flows as high as 53,000 m^3/day (14 mgd) have occurred during rainstorms, but due to a relatively low average annual precipitation, these short-term peaks are infrequent.

The primary treatment facilities were constructed in 1959, and the secondary facilities were added in 1975. The original primary plant consisted of a comminutor, grit chamber, primary clarifier, chlorination facilities, anaerobic digesters, and sludge drying beds. The upgrade in 1975 consisted of a second grit chamber, second comminutor, ABF towers, two secondary clarifiers, additional chlorination facilities, and new sludge disposal facilities. In 1978, short-term aeration facilities were completed.

Treated wastewater discharges through an open ditch to Prickly Pear Creek, which is about 1.6 km (1 mi) north of the plant. Prickly Pear Creek flows another 8 km (5 mi) north into Lake Helena. The discharge permit has been established based on secondary treatment effluent standards. The maximum discharge concentrations of BOD_5 and TSS are 30 mg/l on a 30-day average and

TABLE 1. HELENA YEARLY-AVERAGE INFLUENT WASTEWATER CHARACTERISTICS

Year	Wastewater Flow (mgd)*	Raw Wastewater BOD_5 (mg/l)	Raw Wastewater TSS (mg/l)
1977	3.42	187†	190†
1978	3.27	187†	168†
1979	3.57	156§	190§

*mgd x 3,785 = m^3/day

†Concentration based on 20-hr composite samples collected 5 times/wk.

§Concectration based on 20-hr composite samples collected 7 times/wk.

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45 mg/l on a 7-day average. In addition, the permit requires a minimum of 85 percent removal of BOD_5 and TSS. The 85-percent removal stipulation requires lower discharge BOD_5 and TSS concentrations when the influent wastewater BOD_5 and TSS concentrations are less than 200 mg/l.

During the design of the secondary addition, two main alternatives were considered. One was a conventional activated sludge process followed by aerated lagoons, and the second was the ABF process. It was felt by the design engineer that periodic high hydraulic loadings on the plant, as would occur during a rainstorm, would be detrimental to the conventional activated sludge alternative. As such, the aerated lagoons following this process were included in the conceptual plan for purposes of treating excess flows and to provide an additional treatment safeguard during plant upsets. When these two major alternatives were compared, the ABF process (without short-term aeration) was selected due to the following considerations:

1. Simplicity and ease of operation.

2. Lower construction cost*. The ABF system was projected to result in a lower construction cost of approximately $210,000.

3. Lower operating costs*. Power costs for the ABF system were estimated to be less than 40 percent of the conventional activated sludge system.

The performance of the originally installed ABF process did not meet discharge permit requirements during the winter months of the year, and a decision was made to add short-term aeration. This addition improved system performance, but also increased system cost so that the overall savings were less than indicated above. Each cost comparison between the ABF process and other processes will be unique to a particular situation and must be based on comparative unit processes. The information contained herein will assist the design engineer in selecting system component sizes for the ABF process.

PURPOSE AND SCOPE

This research project involved a full-scale evaluation of the ABF secondary treatment process. The primary objective was to document the performance and operating characteristics of the Helena municipal system at varying conditions including system design loadings. Additional objectives were to document energy requirements, evaluate temperature effects, determine system stability, evaluate sludge settling characteristics, establish sludge wasting requirements, and determine system operational requirements. An effort was also made to identify the relative activities of the bio-cell unit and the short-term aeration unit in sharing the organic load to the system.

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*The cost comparisons were based on design loading conditions, assuming both alternatives provided the same degree of treatment.

A detailed evaluation of the operation and performance of the ABF system was conducted over a 17-mo period. Data collection phases were selected to include two cold weather operating periods and one warm weather period. Three different loading conditions, Periods A, B, and C, were evaluated by removing various units of the ABF process from service. A fourth loading condition, Period D, occurred when the primary clarifier malfunctioned and raw wastewater was directed to the bio-cell. Subsequent to the research project, additional information was collected at Period B loadings. This phase was called Period B'. Period B' was included because operational problems during Period B resulted in questionable data with respect to ABF process capability. The schedule for the different periods is summarized in Table 2.

TABLE 2. DATA COLLECTION SCHEDULE FOR THE EVALUATION PERIODS

Period	Dates	No. of Weeks	Description
A	12/1/78 to 2/22/79	12	Full bio-cell and full aeration basin in service
B	2/23/79 to 7/12/79	20	Half bio-cell and full aeration basin in service
Repair time	7/13/79 to 8/2/79	3	Half bio-cell in service. Aeration basin down for modifications
C	8/3/79 to 1/10/80	23	Half bio-cell and half aeration basin in service
D	1/11/80 to 2/28/80	7	Half bio-cell and half aeration basin in service; primary clarifier out of service most of the time
B'	3/21/80 to 7/10/80	16	Half bio-cell and full aeration basin in service

SECTION 2

CONCLUSIONS

1. Helena's ABF system achieved satisfactory performance when operated at three different loading conditions over a substantial temperature range.

    Process performance was compared to federally-defined secondary treatment criteria. It appears that the ABF process can meet all secondary treatment standards at Period A and Period B loadings if operational practices are optimized. Standards can also be met at Period C loadings, except possibly the 85-percent BOD_5 removal efficiency requirement when raw wastewater BOD_5 concentration is relatively weak.

    The best assurance for consistently meeting standards appears to exist when the aeration basin size is somewhat larger than that recommended by the process manufacturer, Neptune Microfloc, Inc.

2. The energy requirements to operate an ABF system appeared to be about 25 percent less than the energy required to operate a conventional activated sludge system. A potential for additional savings exists by providing the required bio-cell volume with less media depth, assuming treatment performance does not deteriorate.

3. Wastewater temperatures were monitored throughout the study. The primary clarifier temperature ranged from 9 to 19°C. The drop in temperature between the primary and secondary clarifiers averaged only 2 to 3°C, even during the most extreme ambient weather conditions. These conditions included the coldest winter on record for Helena, during which the ambient temperature dropped to -23°C (weekly average).

    No detrimental effect on effluent quality was observed to result from low wastewater temperatures during any of the three loading conditions studied.

    No evidence of freezing was observed in the open-top bio-cell during the project.

4. Helena ABF system performance was observed to be quite stable and reflective of the stability of an attached growth process. Stability was achieved through attainment of relatively fast sludge settling rates throughout the project. As such, no problems were experienced with excessive solids loss from the final clarifiers. The best stability in system performance occurred in Periods C and B' when optimum process control was exercised.

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5. Analysis of sludge wasting data indicated that sludge yield determinations using conventional activated sludge growth theory were not applicable, probably because of the inability to accurately determine or account for the attached growth solids in the bio-cell. It could not be determined whether the ABF process generates more or less biologically-grown sludge solids than does a conventional activated sludge system.

   Secondary system sludge wasting requirements were variable and highly dependent upon "pass-through" as well as biologically-grown solids. Secondary sludge wasting (excluding final effluent solids) averaged 0.95, 1.30, and 1.09 kg TSS/kg $(BOD_5)_R$ during Periods A, B, and C, respectively, and reached 1.86 kg TSS/kg $(BOD_5)_R$ during Period B'. The annual-average wasting rate was about 1.1 kg TSS/kg $(BOD_5)_R$ and appeared to be independent of the process loadings evaluated. As with any biological wastewater treatment process, sludge treatment and disposal facilities for the ABF process must be large enough to handle annual-average secondary sludge wasting needs, as well as the sludge wasting peaks that occur. (Peaks of up to 4 mo in duration and as much as 170 percent of the yearly average were observed.)

6. ABF process control parameters include aeration basin dissolved oxygen (D.O.) concentration, return sludge flow rate, sludge mass wasted, and direct recirculation rate around the bio-cell. Operation with and without direct bio-cell recirculation (return sludge was applied to the bio-cell at all times) led to the belief that this operational procedure had no substantial effect on process performance. The other three process control parameters are similar to those required to operate an activated sludge system. It is believed that manpower requirements for operating and maintaining an ABF system are similar to those required for a similar-sized activated sludge system.

7. In the ABF process, some organic removal occurs in the bio-cell and some in the aeration basin. A straightforward approach to determining the fraction each unit removed was not possible, but data generated revealed trends that can be considered in design. Internal measurements throughout the study indicated that the bio-cell converted all but 8-12 mg/l of the influent soluble BOD_5. This observation, however, was not found to be a valid predictor of the oxygen demand in the aeration basin.

   Graphical analysis of aeration basin oxygen demand provided potentially useful information. At the loadings evaluated, aeration basin oxygen requirements were less than those theoretically necessary for an activated sludge system. The remaining oxygen demand was presumably satisfied in the bio-cell. The bio-cell appeared to satisfy a greater portion of the substrate oxidation requirement in Period A when the full bio-cell was in service.

8. It was determined that an ABF system should not be operated without primary clarification (or fine screening) because of the bio-cell plugging problems that may occur.

SECTION 3

RECOMMENDATIONS

1. Consider the ABF process to be an attractive, highly-competitive secondary treatment option for the following reasons, among others:
    a. The potential exists for 20 percent or greater secondary system energy savings compared to conventional activated sludge.
    b. Stable process control is achieved due to fast sludge settling rates.
2. Consider the following possibilities to further reduce the energy demand of the ABF process:
    a. Reduce bio-cell media depth below the standard 4.3 m (14 ft) where appropriate.
    b. Eliminate or reduce bio-cell effluent direct recirculation.
3. Provide similar O & M manpower for an ABF system as typically provided for a similar-sized conventional activated sludge system.
4. Provide secondary sludge treatment and disposal facilities capable of handling an average waste sludge load of 1.1 kg TSS/kg $(BOD_5)_R$ and peak loads at least 150 percent of this value for periods up to 3 to 4 mo.
5. Selection of design bio-cell and aeration basin loadings will depend on treatment requirements. An analysis of weekly results obtained during Periods A, B', and C lead to the following suggested design parameters for municipal wastewater.

SUGGESTED ABF PROCESS DESIGN PARAMETERS*

Bio-Cell Organic Loading ($lb\ BOD_5/day/1{,}000\ ft^3$)†	System F_A/M Loading§ Effluent BOD/TSS (mg/l)	
	20/20	30/30
80 - 100	0.8 - 1.0	#
150 - 200	#	0.8 - 1.0

*These loadings apply equally to wastewater temperatures ranging from 10 to 20°C.

†$lb\ BOD_5/day/1{,}000\ ft^3 \times 0.016 = kg/m^3/day$

§System F_A/M loading is defined as kg BOD_5 applied to the bio-cell/day/ks MLVSS in the aeration basin.

#These conditions were not evaluated during the project.

SECTION 4

DESCRIPTION OF FACILITIES

The Helena wastewater treatment facilities were designed to provide secondary treatment of wastewater. The primary treatment portion of the plant was constructed in 1959, and the secondary facilities were added in 1975. A design modification that added short-term aeration was completed in April 1978. A flow schematic of the plant as it existed during the research project is presented in Figure 1.

PRELIMINARY TREATMENT FACILITIES

Grit Removal

Raw wastewater enters the influent building from the south and is directed to the No. 1 grit chamber, a square, longitudinal-flow unit. Grit is routinely pumped from the chamber to a cyclone classifier. This pump can be operated manually or by time clock, but is typically run by time clock. Classified grit is collected in a container and periodically hauled to a land disposal site.

Wastewater receives secondary grit removal in grit chamber No. 2 after passing through the comminutor and a flow measurement device. The second grit chamber is used to provide additional protection for the chemical sludge oxidizer. Grit chamber No. 2 is a spiral flow unit with a screw conveyor for grit removal and has a reciprocating rake mechanism for grit classification. Grit is collected in a front-end loader and periodically hauled to a land disposal site. Characteristics of both grit removal facilities are presented in Table 3.

Comminution

The comminutor is located between grit chamber No. 1 and the influent flow measuring device. A "rotogrator" was originally provided as a backup for the comminutor, but was replaced during the project with two bar screens in series (1/9/80). Characteristics of the comminutor, rotogrator, and bar screens are also presented in Table 3.

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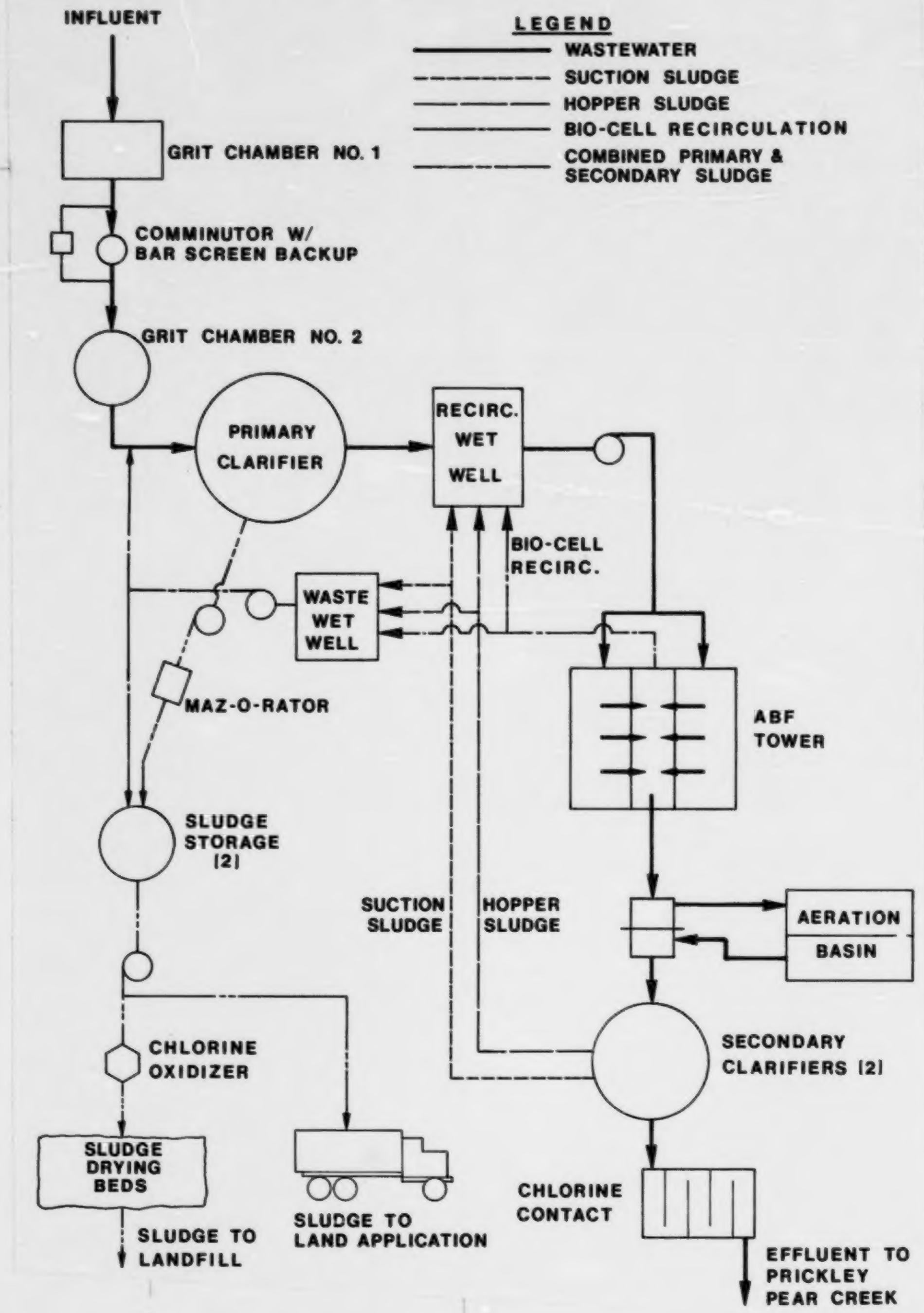
INFLUENT
LEGEND
WASTEWATER
SUCTION SLUDGE
HOPPER SLUDGE
BIO-CELL RECIRCULATION
COMBINED PRIMARY & SECONDARY SLUDGE
GRIT CHAMBER NO. 1
COMMINUTOR W/ BAR SCREEN BACKUP
GRIT CHAMBER NO. 2
PRIMARY CLARIFIER
RECIRC. WET WELL
BIO-CELL RECIRC.
WASTE WET WELL
MAZ-O-RATOR
ABF TOWER
SLUDGE STORAGE (2)
SUCTION SLUDGE
HOPPER SLUDGE
AERATION BASIN
SECONDARY CLARIFIERS (2)
CHLORINE OXIDIZER
SLUDGE DRYING BEDS
SLUDGE TO LANDFILL
SLUDGE TO LAND APPLICATION
CHLORINE CONTACT
EFFLUENT TO PRICKLEY PEAR CREEK

Figure 1. Helena plant flow schematic.

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TABLE 3. PRELIMINARY TREATMENT FACILITIES CHARACTERISTICS

Item	Description
Grit Chamber No. 1	
Basin area	6.1 m x 6.1 m (20 ft x 20 ft)
Mechanism manufacturer	Eimco, Envirotech
Type	B
hp	1 (0.75 kW)
Design removal	90 percent of particles larger than 150 mesh
Design use	Continuous
Grit Chamber No. 2	
Basin diameter	6.1 m (20 ft)
Mechanism manufacturer	Infilco
Type	Vorte-Mix
hp	3 (2.2 kW)
Design removal	100 percent of particles larger than 150 mesh
Design use	Continuous
Comminutor Manufacturer	Worthington
Type	25 - C - 6
hp	1.5 (1.1 kW)
Design use	Continuous
Rotogratог	
Manufacturer	Infilco
Size	43
hp	3 (2.2 kW)
Design use	Backup for comminutor
Bar Screens	
Size	1 @ 5 cm (2 in.) bar spacing followed in series with 1 @ 2.54 cm (1 in.) bar spacing
Design use	Backup for communitor

PRIMARY TREATMENT FACILITIES

Primary clarification of wastewater is provided in a single center-feed sedimentation basin. Also, secondary sludge can be wasted to the primary clarifier for co-settling with primary sludge. Sludge is pumped to the sludge holding tanks for subsequent processing. The sludge pumps can be operated by hand or by a time clock. During the first half of the project, hand operation was employed. During the last half, time clocks were used. Floatable primary materials are removed with a full-radius skimming arm and pumped to the sludge storage tanks. Characteristics of the primary clarification facilities are presented in Table 4.

TABLE 4. PRIMARY TREATMENT FACILITIES CHARACTERISTICS

Item	Description
Clarifier Basin	
Number	1
Diameter	25.9 m (85 ft)
Water depth (shallowest)	3.4 m (11 ft)
Water depth (deepest)	4.3 m (14 ft)
Weir location	Perimeter
Weir length	81.4 m (267 ft)
Surface area	527 m^2 (5,672 ft^2)
Design flow	22,700 m^3/day (6.0 mgd)
Weir overflow rate (design)	279 m^3/day/m (22,500 gpd/ft)
Surface overflow rate (design)	43 $m^3/day/m^2$ (1,060 gpd/ft^2)
Volume	1,926,600 l (509,000 gal)
Hydraulic detention time (design)	2.04 hr
Clarifier Mechanism	
Manufacturer	Infilco
Type	BF
Scum Removal	
Collector	Full-radius arm
Remover	Submerged pipe
Remover operation	Manual/automatic
Scum pump	See sludge pump below
Scum disposal	Sludge holding tank
Sludge Removal	
Sludge type	Primary (and secondary)
Hopper volume	757 l (200 gal)
Sludge and scum pumps	
Number	2
Manufacturer	Moyno
Type	CDQ
Capacity	1.65 l/rotation(0.435 gal/rotation)
Max. rpm	300
hp	7.5 (5.6 kW)
Sludge discharge	Sludge holding tanks

SECONDARY TREATMENT FACILITIES

The secondary system includes a recirculation wet well and pumping facilities, an ABF bio-cell, aeration facilities, secondary clarifiers, and sludge return and wasting facilities.

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Recirculation Wet Well and Pumping Facilities

Primary clarifier effluent flows by gravity to the recirculation wet-well where it combines with return sludge from the secondary clarifiers to form mixed liquor, which is pumped to the top of the ABF bio-cell. Additionally, mixed liquor could be recirculated directly from the bottom of the bio-cell to the wet well so that a desired bio-cell wetting rate could be maintained. This method of direct recirculation was used during Period A only.

Four constant-speed centrifugal pumps, operated with a float system, direct the secondary recirculation wet well contents to the top of the bio-cell. Each pump is powered by an electric motor. As a standby, pump No. 4 can also be powered by a natural gas fueled electrical generator. Characteristics of the recirculation facilities are included in Table 5.

TABLE 5. RECIRCULATION WET WELL AND PUMPING FACILITIES CHARACTERISTICS

Item	Description
Recirculation Wet Well	
Flows received	Primary effluent ABF bio-cell recirculation Return sludge
Surface dimensions	8.2 m x 4.6 m (27 ft x 15 ft)
Depth	3.0 m (10 ft)
Operating volume	45,400 l (12,000 gal)
Recirculation Pumps	
Manufacturer	Allis-Chalmers
Model	150
Nos. 1 & 4	
Size	16 x 16 x 20
hp	75 (56 kW)
rpm	700
Capacity	40,900 m^3/day (7,500 gpm)
No. 2	
Size	12 x 12 x 15
hp	40 (30 kW)
rpm	1,170
Capacity	18,000 m^3/day (3,300 gpm)
No. 3	
Size	14 x 14 x 17-1/2
hp	50 (37 kW)
rpm	695
Capacity	22,900 m^3/day (4,200 gpm)

ABF Bio-Cell

The ABF bio-cell consists of two towers in a common enclosure situated adjacent to each other. Each tower is structurally and functionally independent of the other; however, they shared a common influent pipe and a common effluent channel. Flow from the recirculation pumps is split to two distribution headers, one serving each tower. Valves are available such that one tower can be operated at a time. During Period A, both towers were in service. During Periods B, C, D, and B', one tower was removed from service.

The bio-cell is packed with horizontal, redwood-slat media. The dry specific surface area of the media is 46 m^2/m^3 (14 ft^2/ft^3). A larger undetermined operating specific surface area is achieved because of biomass build-up. The bio-cell flow distribution system consists of 80 fixed, "variflow" nozzles manufactured by Neptune Microfloc, Inc.

Mixed liquor is collected at the bottom of the bio-cell in an effluent trough and directed to the short-term aeration basin, back to the recirculation wet-well for recirculation to the top of the tower, or directly to the secondary clarifiers. The proportion of mixed liquor flow recirculated directly can be adjusted by movable gates within the effluent trough and/or by a valve. Characteristics of the ABF bio-cell are presented in Table 6.

Aeration Facilities

Short-term aeration facilities are located between the ABF bio-cell and the secondary clarifiers. A flow diversion box is provided such that bio-cell effluent can be directed through the aeration basin or diverted directly to the secondary clarifiers. The aeration basin is designed to be used in series with the bio-cell.

The aeration basin is divided into two compartments connected by an overflow opening. The concrete wall separating the compartments is not structurally designed so that one compartment can be dewatered while the other is full. Several openings at floor level insure an equal liquid level on each

TABLE 6. ABF BIO-CELL CHARACTERISTICS

Item	Description
No. towers	2
No. cells	4
Model	2464
Freeboard	1.2 m (4 ft)
Media depth	4.3 m (14 ft)
Surface area per tower	14,358 m (1,536 ft^2)
Total surface area	2,855 m^2 (3,072 ft^2)
Media volume per tower	609 m^3 (21,500 ft^3)
Total media volume	1,218 m^3 (43,000 ft^3)
Design wetting rate	61-204 $l/min/m^2$ (1.5-5 gpm/ft^2)

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side of the wall. During Periods A, B, and B', both aeration compartments were in service. During Periods C and D, one aeration compartment was removed from service. The structural integrity of the dividing wall was maintained by keeping the non-operating side full of water. This side was also aerated to keep from freezing.

Aeration is provided by three blowers through a grid system of static tube diffusers. The blowers are all one size, but have various size pulleys to change blower rpm and thus provide three different air supply possibilities. During the project, one of the three blowers was operated all the time. During the warm summer months it was occasionally necessary to place two blowers on line. Characteristics of the short-term aeration facilities are given in Table 7.

Secondary Clarification

Two circular clarifiers with center inlets and peripheral overflow weirs are provided for secondary clarification. The amount of flow directed to each clarifier is determined by the relative elevations of the clarifiers' overflow weirs. However, the flow to either clarifier could be shut off or partially obstructed with gates at the flow splitting box. Characteristics of the clarifiers are shown in Table 8.

TABLE 7. AERATION SYSTEM CHARACTERISTICS

Item	Description
Aeration Basin	
No. cells	2
Surface area	223 m^2 (2,400 ft^2)
Operating depth	4.6 m (15 ft)
Total volume	1,019,300 1 (269,300 gal)
Wastewater detention time (design)	65 min
Blowers	
Manufacturer	Roots
Type	714 Whispair
Motor hp	75 (56 kW) @ 1775 rpm
No. 1	
rpm	1,560
m^3/min (cfm)	32 (1,130)
No. 2	
rpm	1,125
m^3/min (cfm)	21 (732)
No. 3	
rpm	1,250
m^3/min (cfm)	24 (846)
Air Diffusers	
Manufacturer	Carter
No. diffusers	72
Type	Static tube

TABLE 8. SECONDARY CLARIFIER CHARACTERISTICS

Item	Description
Clarifier	
Number	2
Diameter	22.9 m (75 ft)
Water depth (shallowest)	3.2 m (10.5 ft)
Water depth (deepest)	4.1 m (13.5 ft)
Weir location	Perimeter
Total weir length	144 m (471 ft)
Total surface area	821 m^2 (8,836 ft^2)
Design flow	22,700 m^3/day (6.0 mgd)
Weir overflow rate (design)	158 m^3/day/m (12,700 gpd/ft)
Surface overflow rate (design)	27.7 m^3/day/m^2 (680 gpd/ft^2)
Total volume	2,876,600 1 (760,000 gal)
Hydraulic detention time (design)	3.04 hr
Clarifier Mechanism	
Manufaturer	Eimco, Envirotech
Scum removal	None
Sludge removal	Suction parts and hopper
hp	0.75 (0.56 kW)

Sludge Return and Wasting Facilities

Sludge settled in the secondary clarifiers is returned to the recirculation wet-well to combine with primary effluent to form mixed liquor. Sludge return is possible from either or both of two sludge return mechanisms: the rapid withdrawal "suction" sludge removal mechanism or the sludge hoppers fed by the scraper mechanism. During the project, only the rapid withdrawal sludge removal mechanism was used to return sludge to the wet-well. Each clarifier has eight rapid withdrawal ports (four on each arm) that discharge to the center well. Flow through each port can be shut off or restricted by a slide gate. Sludge withdrawal from individual ports can be sampled and balanced by restricting the flow from the individual ports. The total return sludge flow from both clarifiers is controlled by a butterfly valve on the return sludge line. A sample of the combined return sludge flow from both clarifiers is collected at a sample tap in the recirculation building.

Secondary sludge can also be recycled from the secondary clarifier via sludge hoppers. A sludge hopper is located in each clarifier. Sludge from both hoppers can be combined in a single return line and directed to the recirculation wet-well. Flow volume can be shut off or restricted with a valve. The maximum flow rate of sludge from the hoppers represents about one-ninth of the design total sludge return capacity. Sludge recycle from the hoppers was not used during the project. Both return sludge lines are equipped with flow monitoring capability, which is described later.

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Sludge is wasted from the secondary system daily. Sludge can be wasted from three different points: bio-cell direct recirculation flow, "suction" return sludge, and "hopper" sludge. During the project, all secondary sludge was wasted from the secondary clarifier hoppers. This location for wasting was selected because of the ability to waste sludge at a higher solids concentration and thus the lowest waste volume. The lower waste volume reduced the hydraulic loading on the primary clarifier (i.e., where the waste sludge was directed) and also reduced operator time for wasting.

Waste sludge is diverted to a separate wet-well where it is pumped to the primary clarifier, co-settled with primary sludge, and removed to the sludge handling system. Piping is available to allow waste secondary sludge to be pumped directly to the sludge holding tanks. All wasting lines are equipped with flow monitoring equipment, which will be described later. Characteristics of the sludge return and wasting facilities are presented in Table 9.

TABLE 9. SLUDGE RETURN AND WASTING CHARACTERISTICS

Item	Description
Suction Sludge Return	
No. ports per clarifier	8
Suction tube diameter	15 cm (6 in.)
Tube flow control	Slide gate
Return line diameter	36 cm (16 in.)
Return line flow control	Butterfly valve
Minimum flow*	3,000 m^3/day (550 gpm)
Maximum flow	10,600 m^3/day (1950 gpm)
Hopper Sludge Return	
Hopper volume	757 l (200 gal)
Return line diameter	20 cm (8 in.)
Return line flow control	Butterfly valve
Minimum flow*	109 m^3/day (20 gpm)
Maximum flow	1,363 m^3/day (250 gpm)
Sludge Wasting Facilities	
Wet well volume	11,355 l (3,000 gal)
Sludge pumps	
Number	2
Manufacturer	Allis Chalmers
Size	6 x 4 x 10 SC
Capacity	1,635 m^3/day @ 4.0 m (300 gpm @ 13 ft)
hp	2 (1.5 kW)

*Plugging problems occurred below this value.

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DISINFECTION

Effluent from the secondary clarifiers enters a plug flow chlorine contact basin. Chlorinators, located in the sludge oxidation building, dissolve chlorine gas in a small water stream that is injected into the wastewater flow at the inlet to the chlorine contact basin. Characteristics of the contact basin and chlorinators are shown in Table 10.

SLUDGE HANDLING FACILITIES

Primary or combined primary and secondary sludge is pumped from the primary clarifier to sludge storage tanks. The tanks are the converted anaerobic digesters from the original primary treatment plant. Sludge is pumped with variable-speed, positive displacement pumps, and is also directed through a Maz-O-Rator to produce a homogeneous mixture of small particle size. The homongenous sludge in the holding tanks is directed through the "Purifax" sludge oxidizer manufactured by BIF. In the Purifax process, sludge is recirculated through a reactor with a larger pump while chlorine is fed into the sludge with a vacuum-type feeder. Sludge is then forced out of the oxidizer through a pressure control pump operating at 241 kN/m^2 (35 psi). Chlorine is supplied to the oxidizer with a large chlorinator.

Chemically oxidized sludge is dewatered in nine sludge dewatering beds. Sludge is removed from the beds using road maintenance equipment and is hauled to a land disposal site. Characteristics of the sludge handling facilities are presented in Table 11.

FLOW MEASUREMENT

Flow measurement devices are provided to monitor the raw wastewater, biocell direct recirculation, return sludge, and waste sludge flow streams. Raw wastewater flow is measured with a Parshall flume. An indicator is located at the flume; and an indicator, totalizer, and strip-chart recorder are located on the graphic panel in the control building. Wastewater flow is also

TABLE 10. DISINFECTION SYSTEM CHARACTERISTICS

Item	Description
Contact Basin	
Length to width ratio	102
Volume	732,400 1 (193,500 gal)
Detention time (design)	46 min
Chlorinator	
Number	1
Manufacturer	Advance
Capacity	227 kg/day (500 lb/day)
Type injection	Water
Diffuser	Perforated pipe

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TABLE 11. SLUDGE HANDLING SYSTEM CHARACTERISTICS

Item	Description
Sludge Pumps	
Number	2
Manufacturer	Moyno CDQ
hp	7.5 (5.6 kW)
Capacity	1.65 l/rev (0.435 gal/rev)
Max. rpm	300
Maz-O-Rator	
Manufacturer	Moyno
Model	10 HPX
Size	25 cm (10 in.)
hp	10 (7.5 kW)
Holding Tanks	
Number	2
Diameter	13.7 m (45 ft)
Total volume	2,085,500 l (551,000 gal)
Purifax Chemical Oxidizer	
Number	1
Manufacturer	BIF
Model	236-208-4P
Feed pump capacity	589 m^3/day (108 gpm)
Feed pump hp	7.5 (5.6 kW)
Recirculation pump capacity	4,200 m^3/day (770 gpm)
Recirculation pump hp	30 (22 kW)
Pressure control pump	241 kN/m^2 (35 psi)
Pressure control pump hp	10 (7.5 kW)
Maximum solids concentration	3.5 percent
Chlorinator	
Number	1
Manufacturer	Advance
Capacity	3,629 kg/day (8,000 lb/day)
Chlorine Evaporator	
Number	1
Manufacturer	Advance
Capacity	1,814 kg/day (4,000 lb/day)
Sludge Dewatering Ponds	
Number	10
Total area	4.6 ha (11.4 ac)
Ultimate Dispoal	Burial at disposal site

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measured at the effluent of the chlorine contact tank. The primary function of this measurement is to pace the chlorine feed rate of the chlorinator. No totalizer or recorder is operated in conjunction with this equipment.

Bio-cell direct recirculation and "suction" return sludge flow rates are indicated, recorded, and totalized on the graphic panel located in the control building. Waste sludge flow from the "hopper" is indicated and totalized on a meter located in the secondary recirculation building, next to the waste sludge flow control valve. Flow indicators are also available for mixed liquor waste from the bio-cell recirculation line, "suction" sludge waste from the return sludge line, and "hopper" sludge return from the waste sludge line. Neither of these meters were used during the research project. The characteristics and types of all flow measurement devices are shown in Table 12.

RESEARCH PROJECT MODIFICATIONS

Some plant modifications were completed during the research project to facilitate data collection and to allow operation at different process loadings. To permit operation at greater aeration tank loading rates, a temporary wooden channel across one compartment of the two-compartment aeration basin was installed so that half the basin could be removed from service. Modifications to the air piping were also necessary and were completed during the 3 wk between Periods B and C. Additionally, the aeration blowers were modified by installing various size pulleys to achieve more precise control over the aeration basin D.O. concentration. Flexibility in the existing plant equipment and piping was used to achieve all other process loading and control changes.

To facilitate data collection, two Isco Model 1680 RW refrigerated automatic samplers were purchased to collect samples 24 hr/day on the primary and secondary clarifier effluent streams. Strip chart recorders were purchased for the existing bio-cell recirculation and return sludge flow measuring instruments. Watt-hour meters were rented and installed to measure energy used by the recirculation pumps, aeration blowers, and waste sludge pumps. Modifications were made to provide more laboratory space for the additional analyses conducted during the project. Also, a small laboratory area was constructed in the recirculation building to allow for better process control testing. Sludge direct recirculation, sludge return, and sludge wasting sample taps were installed to aid in sample collection.

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TABLE 12. FLOW MEASUREMENT CHARACTERISTICS

Item	Description
Raw Wastewater	
Control section	61 cm (24 in.) Parshall flume
Transmitter	Sparling 261
Recorder	Sparling 219-M
Flow range	0-56,800 m^3/day (0-15 mgd)
Totalizer	Yes
Plant Effluent	
Control section	Cipolletti weir
Transmitter	Sparling Type 261
Indicator	Sparling Model 903
Flow range	0-56,800 m^3/day (0-15 mgd)
Totalizer	No
Bio-Cell Direct Recirculation	
Control section	Sparling 100 tube meter
Transmitter	Sparling 249-P
Recorder	Sparling 740
Flow range	0-37,850 m^3/day (1-10 mgd)
Totalizer	Sparling 798
Suction Sludge Return	
Same as bio-cell recirculation	
Flow range	0-18,900 m^3/day (1-5.0 mgd)
Hopper Sludge Return	
Control section	Sparling 100 tube meter
Transmitter	Sparling 249-B
Indicator	Sparling 221-M
Flow range	0-5,450 m^3/day (0-1,000 gpm)
Totalizer	Yes
Bio-Cell Mixed Liquor Waste	
Same as hopper sludge return	
Flow range	0-3,270 m^3/day (0-600 gpm)
Suction Sludge Waste	
Same as hopper sludge return	
Flow range	0-2,725 m^3/day (0-500 gpm)
Hopper Sludge Waste	
Control section and transmitter	Sparling 500 flow meter system
Flow range	0-3,815 m^3/day (0-700 gpm)
Indicator	Sparling 780
Totalizer	Sparling 798

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SECTION 5

DATA COLLECTION PROCEDURES

SAMPLE COLLECTION

Numerous samples were collected and analyzed for monitoring plant performance and making operational control decisions. For monitoring plant performance, composite samples were collected, but analysis of certain parameters required that grab samples be obtained or in-situ analyses be conducted.

Composite samples of both the primary and secondary effluent were obtained by collecting discrete samples each hour using ISCO Model 1680 RW refrigerated automatic samplers and then manually compositing the discrete samples proportional to flow. Initially, raw wastewater composite samples consisted of 10 flow-proportioned grab samples collected every 2 hr from 0700 to 0100 hr. However, an additional ISCO sampler was purchased and used for raw wastewater sampling beginning in November 1979. Composite samples were collected each day Monday through Thursday, and analyzed the following day. On Friday, Saturday, and Sunday, a single flow-proportioned composite sample was collected. This single 3-day composite sample was analyzed on Monday. This procedure was implemented to provide a 7-day/wk sampling schedule without requiring additional laboratory staff.

Mixed liquor and waste sludge composite samples were also collected daily and analyzed 5 times/wk. Return sludge composite samples were collected and analyzed 2 days/wk. Mixed liquor and return sludge grab samples were taken 5 times/day and combined in equal volumes to form the composite samples. Waste sludge samples were composited proportional to waste flow. A grab sample of bio-cell effluent was taken 3 times/day, 2 days/wk. The sample was settled until a sufficient and equal volume of supernatant could be obtained and combined to form a composite sample. A summary of the lab analyses conducted on the samples collected is shown in Table 13.

Samples collected and analyzed for the purpose of implementing process control were obtained 5 times/day (0700, 1100, 1500, 1900, and 2300 hr). Analyses conducted on these samples included sludge settling, oxygen uptake rate (OUR), percent solids by volume using a centrifuge, turbidity, sludge blanket depth, D.O., and temperature. Samples for return and waste sludge were collected from taps located in the recirculation building, while other samples were collected at the process units. A summary of the operational control testing schedule is shown in Table 14.

TABLE 13. LABORATORY ANALYSES FOR MONITORING PERFORMANCE

Monitoring Analysis†	Raw Wastewater	Primary Effluent	Secondary Effluent	Bio-Cell Effluent	Aeration Tank Effluent	Return Sludge	Waste Sludge
Total BOD_5	5/wk*	5/wk*	5/wk*				
Soluble BOD_5		2/wk	2/wk	2/wk			
Total COD	5/wk*	5/wk*	5/wk*				
Soluble COD		2/wk	2/wk	2/wk			
TSS	5/wk*	5/wk*	5/wk*		5/wk*	2/wk	5/wk*
VSS		5/wk*			5/wk*	2/wk	5/wk*
pH	1/wk	1/wk	7/wk	7/wk	7/wk		
D.O.	1/wk	1/wk	1/wk	7/wk■	7/wk■		
Alkalinity§	2/mo	2/mo	2/mo				
NH_4^+-N§	2/mo	2/mo	2/mo				
TKN§	2/mo	2/mo	2/mo				
NO_2^-/NO_3^--N§	2/mo	2/mo	2/mo				
Total P§	2/mo	2/mo	2/mo				
Temperature#	1/wk	1/wk	1/wk	7/wk	7/wk		

*Analysis 5 times/wk with 3-day weekend composite sample analyzed on Monday.

†Composite samples except for pH, D.O., and temperature.

§Alkalinity and nutrient analyses later reduced in frequency to 1/mo.

#Ambient temperature taken 5 times/day and averaged.

■Aeration and bio-cell D.O. taken 3 times/day and reported as average.

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TABLE 14. ANALYSES CONDUCTED FOR CONTROLLING ABF PROCESS

Operational Control Test	Bio-cell Effluent (tests/day)	Aeration Tank Effluent (tests/day)	Secondary Effluent (tests/day)	Return Sludge (tests/day)	Waste Sludge (tests/day)
Centrifuge		5	5†	5	as needed when wasting
Sludge Settling		3			
Oxygen Uptake Rate (OUR)	3*	5			
Turbidity			5		
Sludge Blanket Depth			5		
D.O.		3			
Temperature		3			

Continuous Measurement Montoring

Raw wastewater flow	Indicated, recorded, totalized
Final clarifier return sludge flow	Indicated, recorded, totalized
Final clarifier waste sludge flow	Indicated, totalized
Bio-cell direct recirculation flow	Indicated, recorded, totalized
Bio-cell pump electrical energy	Totalized
Aeration blower electrical energy	Totalized
Waste sludge pump eletrical energy	Totalized

*Bio-cell OUR was conducted 2 days/wk. All other testing was done 7 days/wk.

†Core sampler used to obtain sample for clarifier solids determination by centrifuge.

ANALYTICAL PROCEDURES

The original Helena laboratory was capable of analyzing TSS, BOD, pH, temperature, D.O., coliforms, and chlorine residual. The capability to analyze for COD, phophorus, alkalinity, and the nitrogen forms was developed for the research project.

An outline of the specific laboratory procedures used is shown in Table 15. Reagent grade chemicals meeting ASC specifications were used for all reagents, and Class A volumetric glassware was used for reagent preparation. Standard sample solutions were run with each analysis set.

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TABLE 15. LABORATORY PROCEDURES USED FOR ANALYTICAL TESTING

Analysis	Procedure	Comment
BOD_5 and Soluble BOD_5	*Std.Methods p. 543. Soluble BOD sample filtered before analysis	In-bottle dilutions, 3 dilutions per sample, 2 blanks per analysis period. D. O. measurements made using electronic meter with polarographic membrane electrode.
COD and Soluble COD	Std. Methods p. 550-554. Soluble COD sample filtered before analysis.	High level COD procedure used with 20-ml aliquot. Standard solution of KHP run with each set.
TSS and VSS	Std. Methods p. 94-95	47-mm glass fiber filters used with stainless steel funnel.
Alkalinity	Std. Methods p. 278-282	Potentiometric titration to pH 4.5. H_2SO_4 titrant standardized with Na_2CO_3 solution.
NH_4^+-N	†EPA Manual p. 159-164	Micro-distillation procedure used with titrimetric determination. Standard solution of NH_4Cl run with each set.
TKN	EPA Manual p. 175-181	Micro distillation procedure used with titrimetric determination. Standard solution of KNO_3 run with each set.
NO_2^- + NO_3^--N	EPA Manual p. 201-206	Cadmium reduction method used with filtered samples. Standard solution of NH_4Cl run with each set.
Total Phosphorus	EPA Manual p. 251-255	Persulfate digestion method used. Phenolthalien used for pH adjustment. Standard solution of KH_2PO_4 run with each set.
pH	---	Digital pH meter with combination gel electrode used. Calibration prior to each use.
D.O.	---	Electronic meter with polorographic field D.O. Probe used.

*Standard Methods for the Examination of Water and Wastewater, 14th Ed., 1975, APHA-AWWA-WPCF.

†Methods for Chemical Analysis of Water and Wastes, EPA-625-6-74-003.

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QUALITY ASSURANCE

Precise analytical results were obtained for the research project by implementing a quality assurance program. The program involved developing good laboratory procedures, using good equipment, maintaining meters for accurate volumetric flow and electrical power measurements, and implementing good sample collection and handling procedures. Following is a description of some of the highlights of the various phases of the quality assurance program.

Laboratory

Special handling procedures for new and existing laboratory equipment were implemented. All pipets and standard laboratory glassware were washed with laboratory detergent and rinsed with tap water, then with distilled water. Volumetric glassware was cleaned with chromic acid followed by distilled water rinsing. All glassware was air dried following cleaning. The electronic D.O. meter sensing probe was checked for proper membrane condition, then air calibrated and confirmed before each use. The BOD incubator was maintained at 20°C and checked daily using a standardized thermometer. BOD dilution water was stored in glass bottles with cotton plugs. The storage bottles were washed after each use prior to refilling. The drying oven and muffle furnace were checked daily to insure that the temperature was maintained at 103°C and 500°C, respectively. The analytical balance was checked for proper adjustment before each use. Standard weights were used monthly to check relative accuracy and proper scale deflection. The balance was cleaned and serviced yearly. Distilled water was obtained using an all-glass still. Feed water for the still was filtered and deionized prior to the distillation process. Resulting water had a specific conductance of less than 2 mhos/cm.

To assure reproducibility in laboratory results, duplicate analyses were run on all samples on a periodic basis. Table 16 shows the percentage of duplicate samples analyzed, which range from 14 percent to 45 percent for the various analyses conducted.

A mean percent discrepancy between the duplicate results was calculated as follows and is shown in Table 16.

Example:
Duplicate result 1 = 206 mg/l
Duplicate result 2 = 192 mg/l
Average result = 199 mg/l

Absolute difference between duplicate result and average result = 7 mg/l
Percent discrepancy = (7/199)(100) = 3.5

The percent discrepancy values shown indicate the range of values that could be expected for a particular parameter analyzed. For example, the average raw wastewater BOD_5 concentration during Period A was 175 mg/l and, for duplicate BOD_5 analyses conducted on the raw wastewater, the mean percent discrepancy was 3.9 percent. Therefore, the value of 175 mg/l can be considered precise within a range of 175 ± (175) (0.0039) or 175 ± 7 mg/l.

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TABLE 16. DUPLICATE LABORATORY ANALYSES RESULTS

Parameter	Total Analyses	Total Duplicates	Percent Duplicates	Mean Percent Discrepancy* Period A	Period B	Period C
Raw BOD$_5$	341	49	14	3.9	6.4	5.3
Pri. BOD$_5$	325	53	16	4.1	2.4	4.4
Sec. BOD$_5$	358	65	18	4.2	4.5	5.6
Pri. S-BOD$_5$†	142	46	32	4.1	5.5	6.0
Sec. S-BOD$_5$†	136	39	29	11.4	7.6	7.9
Bio-Cell S-BOD$_5$†	158	69	44	4.9	8.1	6.2
Raw COD	332	49	15	10.3	15.0	7.6
Pri. COD	323	53	16	2.5	2.5	3.3
Sec. COD	354	68	19	9.8	9.1	5.7
Pri. S-COD†	152	51	33	1.0	6.2	2.8
Sec. S-COD†	141	37	26	9.2	10.4	8.2
Bio-Cell S-COD†	164	74	45	5.0	6.8	8.7
Raw TSS	359	52	14	3.0	8.0	7.3
Pri. TSS	334	50	15	4.1	6.2	3.7
Pri. VSS	200	30	15	-	7.0	6.0
Sec. TSS	378	70	18	8.8	9.3	5.4
MLSS	513	140	27	2.2	4.4	2.3
MLVSS	491	134	27	3.6	6.3	4.2
RAS TSS§	249	101	40	4.0	3.6	2.5
RAS VSS§	244	97	40	3.2	5.4	6.7
WAS TSS#	481	119	25	2.0	3.5	2.7
WAS VSS#	473	116	24	3.0	5.3	3.1
COD Standard	218	N/A	N/A	1.6	2.0	1.3

*The percent discrepancy is the absolute difference between the duplicate result and the average value of the results, that quantity times 100, and that quantity divided by the average value of the results. The percent discrepancy values shown are the mean values for the indicated data collection period.

†S-BOD$_5$ or S-COD = soluble BOD$_5$ or soluble COD

§RAS = return activated sludge

#WAS = waste activated sludge

A sampling procedure was implemented whereby samples could be collected every day of the week and the laboratory effort could be completed by the existing staff members. The weekend grab samples (Friday, Saturday, and Sunday) were collected as one composite sample and analyzed on Monday. To determine if the results for the samples collected on Friday would change by the time they were analyzed on Monday, the samples collected on Thursday were analyzed on Friday, refrigerated, and analyzed again on Monday. The results of these special tests are shown in Table 17. There appeared to be a slight

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decrease in the strength of the wastewater (believed to be due to sample degradation) from holding the samples, but the difference was felt to be satisfactory with respect to the limits of the accuracy of the test. It was concluded that the benefit of daily sampling could be achieved without a significant sacrifice in analytical precision.

A demand quality assurance sample received from the U.S. Environmental Protection Agency was analyzed for COD and BOD_5 by the Helena lab. Results are shown in Table 18. A recovery of 98 percent for COD and 92 percent for BOD_5 indicate that satisfactory techniques were being used to achieve accurate results for both the COD and BOD_5 analyses.

TABLE 17. FOUR-DAY HOLDOVER BOD_5 AND COD RESULTS

Date Collected	Primary BOD_5 +1 day (mg/l)	Primary BOD_5 +4 day (mg/l)	Secondary BOD_5 +1 day (mg/l)	Secondary BOD_5 +4 day (mg/l)	Primary COD +1 day (mg/l)	Primary COD +4 day (mg/l)	Secondary COD +1 day (mg/l)	Secondary COD +4 day (mg/l)
11/30/78	105	90	6	10	242	244	56	55
2/22/79	116	104	15	12	230	198	82	84
3/15/79	123	95	16	16	247	236	82	79
11/1/79	124	148	20	22	277	302	62	82
2/13/79	164	152	40	23	292	268	95	75
Average	126	118	19	17	258	250	75	75
Mean	122		18		254		75	
Percent Difference*	-3.2		-5.2		-1.5		0	

*Percent difference is respective to +1 day result.

TABLE 18. EPA QUALITY ASSURANCE SAMPLE RESULTS*

Item	COD	BOD_5
True Value (mg/l)	231	146
Lab Value (mg/l)	227	135
Recovery (%)	98	92

*Sample #276 (demand sample) received from Environmental Monitoring and Support Laboratory, Quality Assurance Branch, Cincinnati, Ohio.

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Plant Metering

To insure that accurate measurements were recorded for the wastewater flow to the plant, an inspection of the influent flow meter was conducted. The influent flow variation to the plant was indicated by a float in a stilling well connected to a Parshall flume. At the beginning of the project, the flow meter's accuracy was determined by measuring the water level in the stilling well of the flume, obtaining a flow rate from an appropriate table for the flume size at Helena, and checking this value against the recorded value on a strip chart recorder located in the control building. The meter was checked each week using this procedure and appeared to be accurately recording the flow. However, 8 wk into the project, a comparison of the strip chart recorded flow with the totalizer flow indicated a discrepancy. To determine the cause of the discrepancy, the flow transmitter unit was positioned to transmit a selected flow rate while the recorder and totalizer values were obtained. The check was made at different flow rates, and the results are shown in Table 19.

The flow totalizer was found to be in error by a consistant value of 3,670 m^3/day (0.97 mgd). It is noted that the historical flows for the Helena plant were strongly suspected to be in error by this same margin and were adjusted accordingly. The meter was recalibrated, checked, and lubricated so that all indicated, recorded, and totalized flows were equally precise. Subsequently, weekly checks were made using the stilling well measurement in comparison with the indicated recorded and totalized flows and no further adjustment was required for the remainder of the project.

The volume of sludge wasted from the secondary system was measured by a propeller flow meter during the first part of the project (until 1/12/79). Calibration checks were made on the accuracy of this meter by directing the

TABLE 19. INFLUENT PARSHALL FLUME FLOW RECORDER VERSUS FLOW TOTALIZER READINGS

Influent Bldg. Flow Indicator (mgd)*	Control Room Flow Recorder (mgd)*	Totalizer Flow (mgd)*	Difference in Flow Totalizer Versus Flow Indicator (mgd)*
Before Correction			
1.96	1.82	2.95	0.99
2.97	2.82	3.95	0.98
3.95	3.80	4.92	0.97
5.05	4.89	6.00	0.95
0.95	0.80	1.93	0.98
		Avg.	0.97
After Correction			
5.20	--	5.20	0
5.35	--	5.33	0.02

*mgd x 3,785 = m^3/day

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measured sludge into a waste sludge holding tank, from which the exact volume of sludge wasted could be calculated. Several calibration checks were required of the propeller meter, and flow correction factors ranging from 1.0 to 1.6 were applied to the indicated values, as necessary. To avoid the extra time for frequent calibration checks and to improve the waste sludge flow measuring system, the propeller meter was removed from service and replaced with a sonic flow meter. The sonic flow meter provided more precise results in that weekly calibration checks showed that this meter was always accurate to within ±2 percent of the value measured volumetrically in the waste holding tank.

The return sludge flow meters could not be checked directly, but were checked indirectly through a solids balance by using the following equation:

$$\text{Percent return} = (R/Q) \times 100 \approx \frac{\text{MLSS} \times 100}{\text{RAS TSS} - \text{MLSS}}$$

where:
R = measured return sludge flow rate
Q = measured wastewater flow rate
MLSS = mixed liquor suspended solids concentration
RAS TSS = return activated sludge suspended solids concentration

The results for Periods A, B, and C are summarized in Table 20. Period D was not included because of known plugging problems with the meter. The solids balance calculated return rate was always slightly higher (i.e., mean 7,911 m^3/day or 2.09 mgd versus 7,192 m^3/day or 1.90 mgd), but was within a 10 percent margin, which was not felt to warrent adjustments to the return sludge flow meter.

As part of the project, three electrical power meters were installed to measure the power required by the recirculation pumps, aeration blowers, and waste sludge pumps. The electrical power meters for these units were single-phase meters, and, therefore, measured only one phase of the three-phase power supply to the motors. An accurate full-power reading would be indicated if

TABLE 20. SOLIDS BALANCE VERSUS MEASURED FLOW RETURN PERCENTAGE VALUES

Period	MLSS (mg/l)	RAS TSS (mg/l)	Solids Balance R/Q (%)	Measured Q (mgd)*	Flow Measured R/Q (%)	Measured R (mgd)*	Calculated† R (mgd)*
A	2,604	7,608	52.0	3.67	48.2	1.77	1.91
B	3,701	10,011	58.7	3.75	52.5	1.97	2.20
C	3,594	9,034	66.1	3.27	60.2	1.97	2.16
Mean						1.90	2.09

*mgd x 3,785 = m^3/day

†Calculated R equals solids balance R/Q times measured Q.

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the power supplied to the motor was equally balanced among the three phases. As a check, amperage readings were taken for each of the three phases of power for the various motors. The power drawn by all motors evidenced a good balance as shown in Table 21. The measured power for the aeration blowers and waste sludge pumps was slightly higher than the average and for the bio-cell pumps slightly lower, but not significantly out-of-line to warrant an adjustment to the recorded electrical usage values. It was concluded that representative power readings were obtained using the single-phase electrical power meters.

Sampling

Nearly all laboratory analyses were conducted on samples collected the previous day. These samples were composited proportional to flow and stored in refrigerated containers. Except for bio-cell OUR, daily operational testing was conducted immediately on grab samples obtained at 4-hr intervals, 5 times/day (i.e., 0700, 1100, 1500, 1900, and 2300 hr). The sample for bio-cell OUR was obtained 3 times/day, 2-days/wk. The mean of these tests represented the average value for that day.

Operational testing time intervals were selected primarily to adapt to existing operator schedules. It was desired to also have these testing frequencies satisfactorily represent the average values for the entire 24-hr time period of the day. In order to verify if the 5 tests (or 3 tests) were

TABLE 21. RESULTS OF POWER METER PHASE BALANCE CHECK

Motor	Phase I (amps)	Phase II (amps)	Phase III* (amps)	Percent Divergence†
Aeration Blowers				
No.1	59	63	62	+1.1
No.2	46	50	50	+2.7
No.3	50	55	53	+0.6
Bio-Cell Pumps				
No.1	105	110	106	-0.9
No.2	48	51	48	-2.1
No.3	59	60	58	-1.7
No.4	105	109	105	-1.3
Waste Pump				
No.5	2.8	3.0	3.0	+2.2

*The phase III leg was the phase measured by the power meters.

†Percent divergence was calculated as the difference between the value for the measured phase and the average of the three phases, that quantity times 100, that quantity divided by the value for the phase measured.

representative of a daily average value, three special tests were conducted whereby samples were collected and tests were completed every hour for 24 hr for four of the most critical operational tests, namely the aeration basin and bio-cell effluent oxygen uptake rate tests and the aeration basin and bio-cell effluent MLSS concentration tests. The results of these tests, shown in Table 22, indicate less than 13 percent difference between the average values of the 5 or 3 tests and the 24 tests for all observations. For most observations, the difference was less than 5 percent. It was concluded that the 5 tests (or 3 tests) were satisfactorily representative of the average result for the entire day.

The OUR tests were conducted in the operations testing area, which was usually warmer than the temperature of the samples. It was felt that a sample temperature increase might occur during the OUR test and produce an increased OUR value. To determine if a change in temperature occurred and was significant, the sample temperature was taken before and after the OUR test. It was found from 11 wk of data that the average temperature increase during the test was less than 1°C. This increase was not felt to be significant. In addition, the D.O. depletion for the OUR test was recorded on a strip chart. It was noted that no variation occurred in the slope of the line during the test. It was concluded that the OUR was not significantly changing during the time the OUR test was conducted. Results of the OUR temperature evaluation are summarized in Table 23.

TABLE 22. AVERAGE DAILY OUR AND MLSS RESULTS FOR 5 TESTS AND 3 TESTS VERSUS 24 TESTS

Parameter	No. Tests	24 Tests	Percent Difference
	5 Tests		
Aeration Basin Effluent:			
Oxygen Uptake Rate (mg/l/hr)			
Period A (1/11/79)	27.0	26.5	+1.9
Period B (5/3/79)	34.8	34.7	+0.3
Period C (10/4/79)	68.6	72.4	-5.5
MLSS Concentration (% volume)			
Period A (1/11/79)	4.3	4.2	+2.4
Period C (10/4/79)	4.8	5.0	-4.2
	3 Tests		
Bio-Cell Effluent:			
Oxygen Uptake Rate (mg/l/hr)			
Period A (1/11/79)	44.9	40.9	+9.8
Period B (5/3/79)	68.9	66.8	+3.1
Period C (10/4/79)	101.2	114.1	-12.7
MLSS Concentration (% volume)			
Period C (10/4/79)	5.3	5.1	+3.9

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TABLE 23. RESULTS OF TEMPERATURE INCREASE DURING CONDUCT OF OUR TEST

Week	Beginning Temp. (°C)	Ending Temp. (°C)	Difference (°C)
10-19-79/10-25-79	16.5	18.3	1.8
10-26-79/11-1-79	15.7	16.9	1.2
11-2-79/11-8-79	14.8	16.1	1.3
11-9-79/11-15-79	13.8	15.3	1.5
11-16-79/11-22-79	14.0	14.5	0.5
11-23-79/11-29-79	13.1	13.3	0.2
11-30-79/12-6-79	13.0	13.6	0.6
12-7-79/12-13-79	12.4	13.3	0.9
12-14-79/12-20-79	11.5	12.3	0.8
12-21-79/12-27-79	11.7	12.7	1.0
12-28-79/1-3-80	11.7	12.4	0.7
Average	13.5	14.4	0.9

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SECTION 6

RESULTS AND DISCUSSION

OPERATIONAL REQUIREMENTS

The ABF process consists of two main components, each of which acts to convert waste material to biological solids. The first component is a bio-cell (redwood tower) and the second an aeration basin. The bio-cell exhibits properties of an attached growth biological process in that a portion of the biological treatment is accomplished by a layer of slime that builds up on the surface of redwood slats. The aeration basin gives the ABF process the properties of a suspended growth biological process in that oxygenation and mixing of a mixed liquor occurs. An additional aspect of the ABF process is the cycling of mixed liquor suspended solids through the bio-cell prior to entering the aeration basin.

Process Control

Numerous operational variables are available with an ABF system, but four controls that most directly relate to performance are: a) direct recirculation rate of bio-cell effluent around the bio-cell, b) aeration basin D.O. level, c) secondary clarifier sludge return rate to the bio-cell, and d) system sludge mass controlled by the sludge wasting rate. Direct recirculation around the redwood tower is an operational control unique to the ABF process. The other three are controls typically associated with suspended growth systems.

During the research project, special emphasis was placed on achieving optimum system control to insure that process capabilities were not limited by operational constraints. For some operational controls, like bio-cell direct recirculation rate, Neptune Microfloc's recommended values were used since evaluation of recirculation rate adjustments on plant performance could not be made within the time frame of the research periods. For other process controls, adjustments were made to achieve the best possible performance.

Neptune Microfloc (1)(2) recommends a bio-cell direct recirculation flow for fixed nozzle distribution systems such that the bio-cell hydraulic loading is held within the range of 61 to 224 $l/min/m^2$ (1.5 to 5.5 gpm/ft^2). Further, they suggest that direct recirculation is more beneficial when using constant-speed pumps than when variable-speed pumps are used. The relatively broad range of recommended hydraulic loading rates indicates that Neptune Microfloc does not closely associate the rate of direct recirculation with process or performance needs. During the project, adjustments were made to keep the bio-cell hydraulic load within the recommended range. A bio-cell recirculation flow of 12,800 m^3/day (3.39 mgd) was maintained in Period A when both bio-cell towers were in service. No bio-cell recirculation flow was required during the other periods when only one bio-cell tower and, thus, less surface area was used. Other process parameters (i.e., D.O., return sludge flow rate, and sludge mass wasted) were routinely adjusted to attempt to optimize the performance of the ABF process.

The operations-oriented testing schedule implemented to achieve process control was presented in Table 14. Most tests were conducted 5 times/day, and the results were compiled on a "Daily Process Control Tests" information sheet. Test results were averaged for the day and transferred to a "Daily Control Calculations" sheet. Daily-average results were compiled into weekly-average results. The weekly-average values were used as the data points for most of the computations and correlations presented in this report. Copies of the "Daily Process Control Tests" information sheet (and associated "Suspended Growth Mass Worksheet"), the "Daily Control Calculations" sheets, an explanation of each column of the Daily Control Calculations sheets, and a completed sample of 28 days (two sheets) of control calculation test results are included in Appendix A.

The aeration basin D.O. concentration was controlled by the number and speed of aeration blowers on line. If the aeration basin D.O. concentration approached 1 mg/l, a higher speed was utilized or more aeration blowers were put in service. Similarly, a slower speed was utilized or fewer blowers were put in service if the D.O. level approached 3 mg/l. The capability to change the speed of the blowers was added shortly after the research project began. Prior to this change, the aeration basin D.O. concentration was almost always greater than 5 mg/l. After the blowers were fitted to operate at different speeds, the weekly average D.O. concentration was greater than 4 mg/l only twice, never less than 1 mg/l, and usually between 1 and 3 mg/l. The blowers were operated by automatic time clocks, and periodic (about once per week) adjustments to the clock settings were made to control the D.O. concentration.

The return sludge flow rate was adjusted to optimize the MLSS concentration in the aeration basin relative to the diurnal wastewater flow variations. A comparison during the project showed that with return adjustments the daily-average variation in the MLSS concentration could be held to 10 percent. Without return adjustment, the variation was 19 percent. When returns were not adjusted, it was noted that the MLSS concentration reached its lowest level of the day when the peak-hourly wastewater flow and organic load were received. To optimize performance, it was felt that return adjustments to keep the MLSS concentration as high as possible during peak loading conditions were justified and a routine return sludge flow adjustment program was implemented.

Neptune Microfloc recommends a 50 percent R/Q ratio (1)(2). During the project, optimum solids distribution was obtained by maintaining the R/Q ratio between 50 and 60 percent, thus supporting this recommendation. Adjustments to the return sludge flow rate were routinely implemented as follows:

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The chief operator periodically (weekly or bimonthly, depending on seasonal flow fluctuations) developed an hourly wastewater flow variation graph as shown in Figure 2. Average wastewater flow rates for 8-hr intervals (i.e., 0700 hr to 1500 hr; 1500 hr to 2300 hr; and 2300 hr to 0700 hr) were then computed. These rates were multiplied by the preselected R/Q ratio to obtain the desired return sludge flow rate. The operators adjusted the return sludge flow rate to this value at the beginning of each 8-hr interval.

Changes were made in the value of the three daily adjustments when the wastewater flow rate changed significantly or when conditions (i.e., settling) indicated that a different R/Q ratio would provide more optimum solids distribution. An exception to this approach was on weekends and holidays when the early morning wastewater flow increase was typically delayed 2 hr. On these occasions, the morning return sludge flow rate adjustment was also delayed 2 hr. Using the above described approach for making return adjustments, optimum solids concentrations in the aerator were approached. Operator attention was necessary to develop and maintain good control over this process variable.

In order to maintain a consistent inventory of suspended sludge solids in the ABF system, special emphasis had to be placed on sludge wasting. Typically, the mean cell residence time (MCRT) was about 2 days, which meant that approximately 50 percent of the suspended sludge mass in the system had to be wasted each day. It is noted that attached sludge in the bio-cell was excluded in all calculations due to the inability to accurately measure the quantity

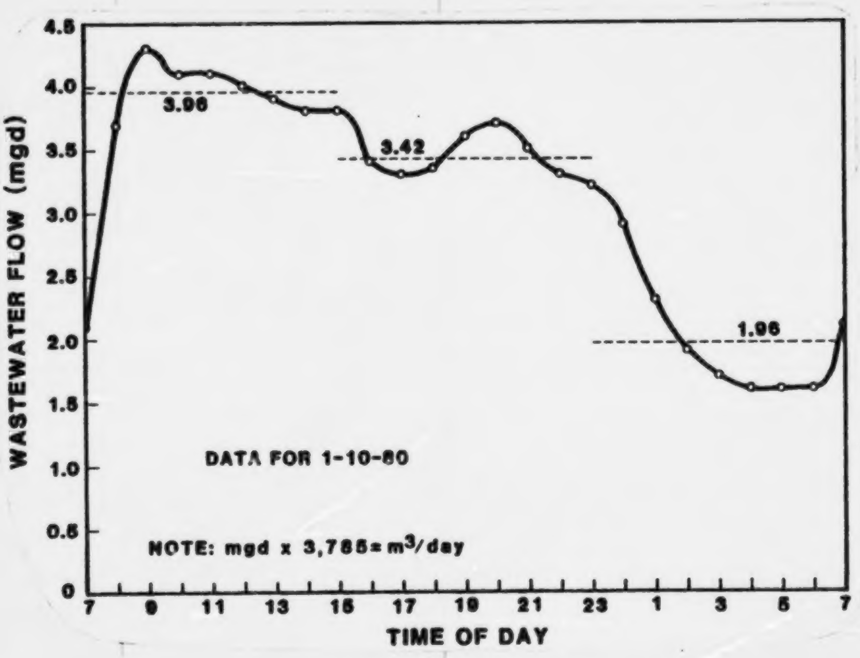

Figure 2. Helena diurnal wastewater flow variation.

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of this sludge. The relationship between the total mass of suspended sludge in the system (including bio-cell suspended solids, clarifier solids, and aeration basin solids) and MCRT during the research project is shown in Figure 3. For the first 28 wk of data collection, selected amounts of sludge were wasted each day to try to maintain a preselected total mass of suspended sludge in the system. During Period A, this approach was satisfactory in terms of achieving a relatively uniform total system sludge mass and MLSS concentration, as shown in Figures 3 and 4, respectively. However, during Period B when half the bio-cell was removed from service, wide fluctuations in both total sludge mass and MLSS concentration occurred and the approach to accomplishing sludge inventory control was modified.

The modification to the sludge wasting program involved having the operators preselect an objective MCRT (instead of preselecting a mass of sludge to waste), and then waste appropriately to reach the objective MCRT. A "Suspended Growth Mass Worksheet" shown in Appendix A was developed for this purpose. The operators wasted 4 times/day based on the results of operations tests.

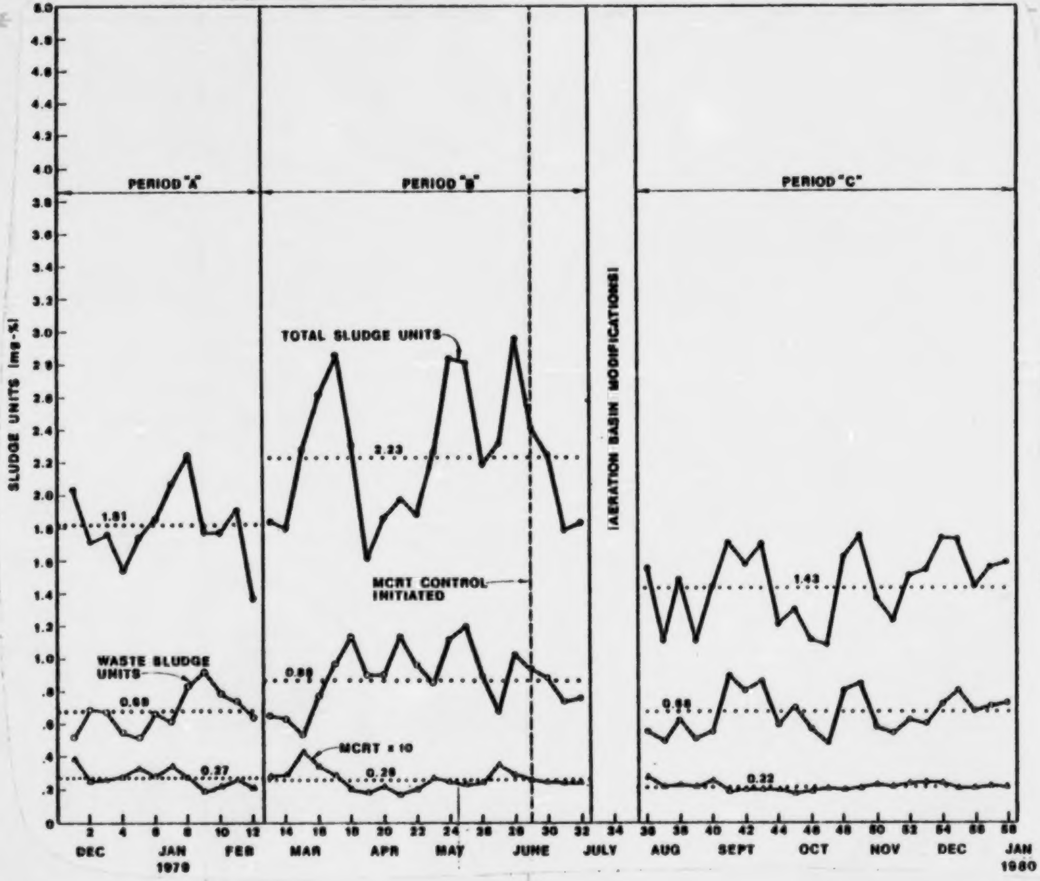

Figure 3. Relationship among total system sludge mass, mass wasted, and MCRT.

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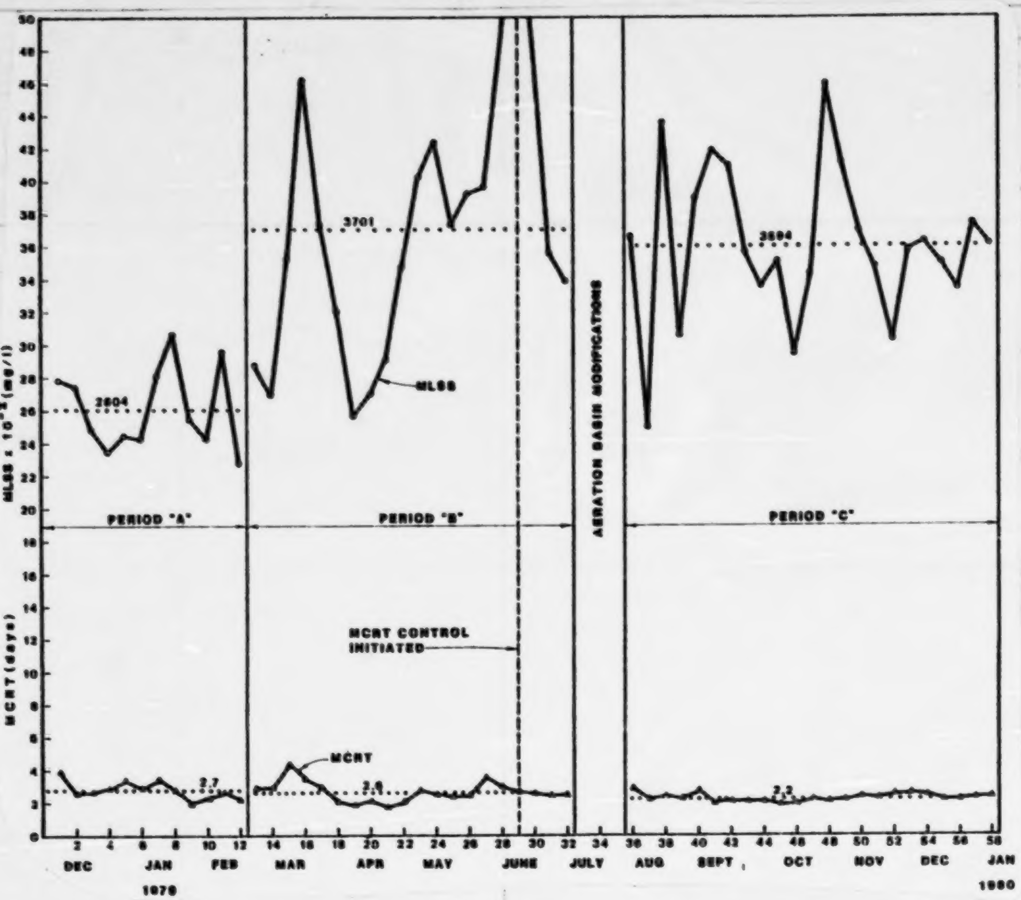

Figure 4. Relationship between MLSS concentration and MCRT.

Approximately one-fourth of the total waste sludge value for the day was wasted each time, with the final wasting period used to achieve that day's desired MCRT and desired mass of sludge wasted from the system.

The MCRT approach to controlling sludge inventory was implemented near the end of Period B and continued through the rest of the project. Using this procedure, less variation occurred with total system sludge mass and MLSS concentrations. The ABF process requires operation at low MCRT values (based on suspended growth only) because of the small aeration basin volume. As such, careful control of wasting is required to avoid wide fluctuations in the MLSS concentration and the use of the preselected MCRT procedure provided the best control.

The testing and adjustment program implemented during the research project provided good control over the ABF process variables. A lesser program would have resulted in wider fluctuations in the MLSS concentration. The program implemented was similar to program requirements for operating a similar-

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sized activated sludge process. It was concluded that manpower requirements for operating an ABF system can be expected to be similar to manpower needs for operating a similar-sized activated sludge process.

The ABF process appeared to not be susceptible to periods during which the sludge settles slowly and exhibits bulking sludge characteristics typical of activated sludge processes. At no time during the project was slow sludge settling experienced; the SVI was almost always between 50 and 150 ml/gm. The absence of bulking sludge characteristics may be associated with the reservoir of attached solids in the bio-cell and the continuous "attached growth" solids slough-off. These solids may be more zoogloeal in nature and thus enhance the rapid settling properties of the suspended solids. However, no microscopic or other testing was completed to support this hypothesis. Whatever the reason, the absence of a sludge demonstrating slow settling characteristics eliminated periods of solids loss from the final clarifiers that are sometimes associated with an activated sludge process. The stable settling characteristics were believed to represent a positive advantage of the ABF process as a secondary treatment alternative.

Maintenance

Maintenance activities to operate an ABF system were evaluated qualitatively as compared to projected maintenance needs of other similar-sized secondary treatment systems. A formal time-in-motion study and/or a maintenance cost breakdown was not completed.

Maintenance activities required for operating an ABF system included maintenance on recirculation pumps, aeration blowers, and diffusers; basin, channel and walkway washdown; and tower cleaning. Tower cleaning consisted of removing debris (1 man-hr effort twice per month) that accumulated in the flow distribution nozzles and on top of the bio-cell media. Maintenance required on aeration blowers and diffusers and basin, channel, and walkway washdown were similar to requirements at facilities using the activated sludge process. Other maintenance activities associated with the recirculation pumps and tower cleaning are unique to the ABF process. Qualitatively, it was believed that the maintenance requirements for the ABF process would probably more closely approximate those of an activated sludge facility than a facility relying totally on an attached growth process.

During the project, a special cleaning maintenance activity was necessary as a result of the primary clarifer being out of service for a significant period of time. During this time (Period D), the raw wastewater passed through the grit removal and screening processes and directly to the ABF tower in service. In about 3 wk, extensive plugging of the tower media occurred, resulting in some ponding on the tower surface. Also, plugging occurred in the sludge return lines from the final clarifiers. Very little plugging occurred in the tower distribution nozzles. Based on this experience, it was concluded that wastewater should not be directed to the ABF process without adequate primary treatment. Because these problems were extensive during Period D, Period D data were not used in the discussion of the performance capabilities of the Helena ABF system.

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UNIT PROCESS PERFORMANCE

The ABF process has two biological units (a bio-cell and an aeration basin) that work together to achieve overall system performance. During this research study, an effort was made to determine the contribution of each unit toward overall system pollutant removal to provide information that could be used to optimize the size of the respective units. Process characteristics plus the range of loading conditions evaluated made this differentiation impractical. However, the evaluation does provide information for calculating aeration basin oxygen demand for two bio-cell organic loading rates.

Sludge solids in an ABF system circulate from the bio-cell to the aeration basin to the final clarifiers and back to the bio-cell several times each day. As an example, during Period C, the sludge made 1 cycle about every 1.3 hr. This rapid cycling of the sludge causes the pollutant removal characteristics of each unit to be dependent upon and heavily influenced by each other.

Three different process loading conditions were evaluated, but the system appeared to function as if only two conditions were evaluated. The resulting two conditions were differentiated by the organic loading on the bio-cell. The full bio-cell was in service during Period A, and one-half of the bio-cell was in service during Periods B and C. Operation of the bio-cell in this manner resulted in a bio-cell organic loading variation of approximately 2:1, but the data indicated that this range of loading was not sufficient to cause a large variation in bio-cell organic removal capability. The average bio-cell effluent soluble BOD_5 for all loadings evaluated varied only from 9 to 11 mg/l.

One cannot conclude from the information above that the bio-cell performed similarly in all respects at both loading conditions. Rather, an indication that the bio-cell responded differently to the loading conditions is evident in the higher oxygen usage rate in the aeration basin observed in Periods B and C than in Period A (Figure 5). It was concluded, therefore, that, for the loadings evaluated, the bio-cell's capability to remove soluble organics is relatively unaffected by organic loading, but the downstream aeration basin oxygen usage demand increases as the bio-cell organic loading rate increases.

ENERGY REQUIREMENTS

Energy to operate the Helena ABF system was required for pumping mixed liquor to the bio-cell and for aeration basin oxygen supply and mixing. Each of these energy consuming areas was measured independently.

Bio-Cell Pumping Energy

The measured specific energy demand for pumping to the bio-cell is shown in Figure 6. Volume pumped included primary effluent and return sludge flow, plus bio-cell direct recirculation flow during Period A. Problems were encountered with the electrical power measuring device during most of Period A. Also, the pumping energy demand increased substantially for several weeks at the end of Period B and in Period C. It was determined that the increase was due to a problem with a valve that increased the pumping head. When the

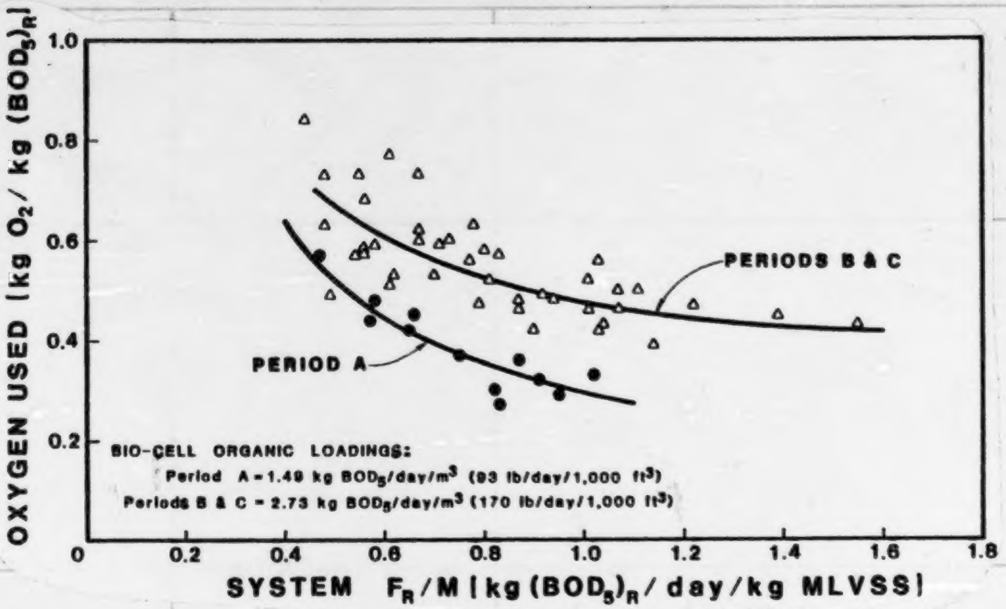

Figure 5. Aeration basin oxygen requirements as a function of system F_R/M loading and bio-cell organic loading.
Note: $(BOD_5)_R$ = Primary effluent total BOD_5 minus secondary effluent soluble BOD_5

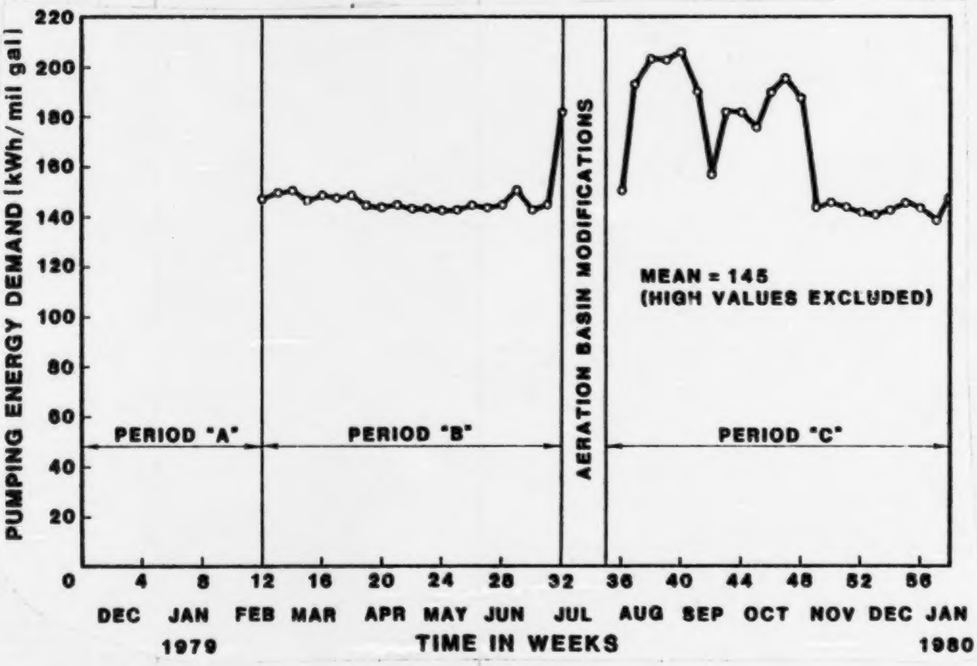

Figure 6. ABF bio-cell pumping energy demand.

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problem was corrected, the pumping energy demand decreased to the recurring value of 38 kWh/1,000 m^3 (145 kWh/mil gal) of liquid pumped.

The operating bio-cell pumping total dynamic head (TDH) at Helena normally varied 0.3 m (1 ft) and averaged 9.8 m (32 ft). At a TDH of 9.8 m (32 ft) and measured energy consumption of 38 kWh/1,000 m^3 (145 kWh/mil gal), the overall pumping efficiency was 69 percent. Assuming a motor efficiency of 90 percent, the average pump efficiency was 77 percent. The four bio-cell pumps had rated efficiencies ranging from 73 to 85 percent at a TDH of 9.8 m (32 ft). Based on this good correlation between rated efficiencies and measured efficiencies, the measured pumping energy demand of 38 kWh/1,000 m^3 (145 kWh/mil gal) will be used for calculating pumping power requirements in the remainder of the report.

The bio-cell pumping energy requirement at Helena was influenced by the process layout, equipment furnished, and operational procedures. For example, during design it was decided to reduce equipment maintenance associated with a separate pump station by lowering the bio-cell recirculation wet-well liquid level to allow gravity return sludge flow. This decision did not increase return sludge pumping energy, but did increase the energy required to pump primary effluent and bio-cell direct recirculation flow because they had to be pumped from an estimated 1.5-m (5-ft) lower elevation, as shown in Figure 7. At Helena, an estimated 10-percent additional pumping cost was required.

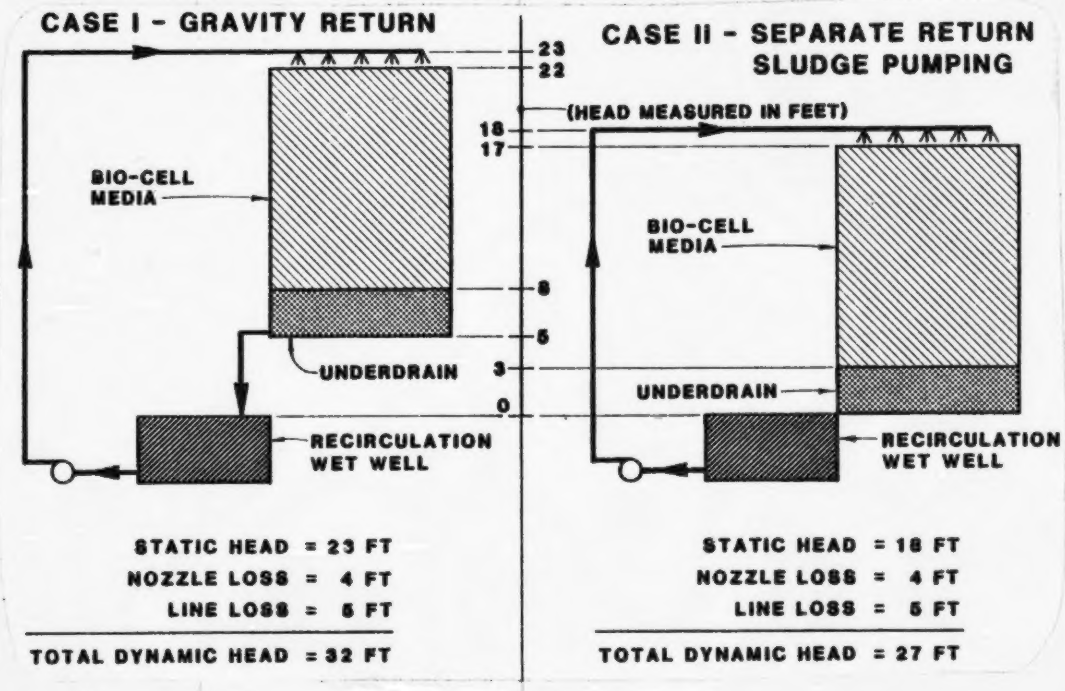
CASE I - GRAVITY RETURN
CASE II - SEPARATE RETURN SLUDGE PUMPING
(HEAD MEASURED IN FEET)
23
22
18
17
8
5
3
0
BIO-CELL MEDIA
UNDERDRAIN
RECIRCULATION WET WELL
BIO-CELL MEDIA
UNDERDRAIN
RECIRCULATION WET WELL
STATIC HEAD = 23 FT
NOZZLE LOSS = 4 FT
LINE LOSS = 5 FT
TOTAL DYNAMIC HEAD = 32 FT
STATIC HEAD = 18 FT
NOZZLE LOSS = 4 FT
LINE LOSS = 5 FT
TOTAL DYNAMIC HEAD = 27 FT

Figure 7. Illustrative diagram of bio-cell pumping system.
Note: ft x 0.305 = m

The type of equipment furnished, namely the height of the bio-cell, significantly affected the pumping TDH and resulting energy demand at Helena. Neptune Microfloc (2) states that bio-cell performance is independent of bio-cell height above approximately 2.1 m (7 ft). The Helena bio-cell is 4.3 m (14 ft) high, which accounts for 44 percent of the existing 9.8-m (32-ft) TDH. Therefore, a 50-percent reduction in bio-cell media depth (i.e., from 4.3 m to 2.1 m (14 ft to 7 ft) would yield a 22-percent reduction in pumping energy demand. Neptune Microfloc (2) has developed the equation shown below for determining optimum bio-cell media height for minimizing pumping cost (not total cost). The equation describes the interrelationship between bio-cell organic and hydraulic loadings as they influence media depth.

$$H_m = \frac{12 \times W_m \times 1^{\circ}}{L \times (Q_{BC}/Q_A)}$$

where: H_m = optimum media depth, ft
W_m = minimum wetting rate, gpm/ft^2
1° = influent BOD$_5$, mg/l
L = organic loading, lb BOD$_5$/day/1,000 ft^3
Q_{BC} = flow to bio-cell, gpm
Q_A = average design flow, gpm

It should be noted that the Helena research project did not address bio-cell media depth versus system performance. The existing bio-cells were evaluated as constructed. The deeper media at Helena was probably utilized because the original ABF process did not include a short-term aeration system. According to the equation and with short-term aeration, the Helena bio-cell could have had at least 1.5 m (5 ft) less depth.

Operational procedures implemented also affect bio-cell pumping energy demand, for example, if bio-cell direct recirculation is provided. During the research project, direct recirculation of bio-cell effluent was not used during Periods B and C, the periods of highest system loading. If a direct recirculation flow of 40 percent of the plant flow rate had been used, the pumping energy demand would have increased by about 27 percent. Therefore, to save energy and operating costs, it is important to avoid recirculating flow directly around the bio-cell unless it is necessary to provide required treatment efficiency.

Aeration Basin Oxygenation Energy

The electrical energy demand for aeration basin oxygen supply was measured with a separate watt-hour meter. The resulting aeration efficiency expressed as mass of oxygen transferred per wire horsepower-hour of electrical energy consumed is shown in Figure 8. The aeration basin oxygen transfer rate was calculated as follows:

$$\text{Oxygen transfer rate} = \frac{\text{Oxygen transferred by blowers}}{\text{Blower power demand}}$$

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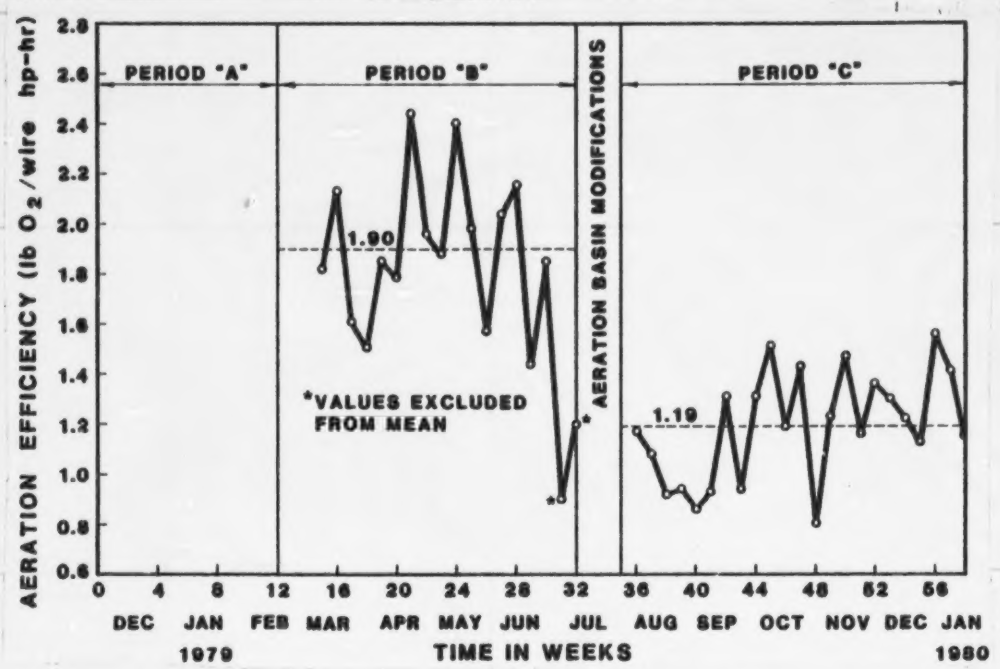

Figure 8. ABF aeration basin oxygen transfer rate.
Note: lb/wire hp-hr x 0.608 = kg/kWh

The blower power demand was measured by the aeration watt-hour meter. The amount of oxygen transferred by the blowers was calculated as follows:

Oxygen transferred by blowers = Measured oxygen uptake rate in aeration basin minus oxygen supplied by bio-cell

where: oxygen supplied by bio-cell = (bio-cell flow in mgd) times (bio-cell effluent D.O. minus aeration basin effluent D.O. in mg/l) times (8.34)

NOTE: The amount of oxygen that was supplied to the aeration basin by the bio-cell effluent varied for each period. In Period A, 82 kg O_2/day (181 lb/day) was supplied by the bio-cell, which was 13.2 percent of the measured aeration basin oxygen uptake rate. Lower percentages of 9.2 percent for Period B and 7.9 percent for Period C occurred. The larger portion during Period A was caused primarily by a lower aeration basin oxygen uptake rate due to the lower bio-cell organic loading when both towers were in service.

Energy demand for aeration was not available for the first part of the research project because of problems with the watt-hour meters. D.O. results for the last 2 wk of Period B indicated that an extra blower was required. It was later determined that the D.O. results were questionable, and an additional blower was not necessary. As a result, energy consumption values for these weeks were excluded from the analysis of Period B data. As shown in Figure 8, the mean aeration efficiency was 1.16 kg O_2/kWh (1.90 lb/wire hp-hr) for Period B and 0.72 kg O_2/kWh (1.19 lb/wire hp-hr) for Period C. The lower measured values for Period C occurred because one-half of the aeration basin was removed from service for wastewater treatment, but air was supplied to both halves of the basin. More air was supplied to the treatment half, but an undetermined volume of air was also supplied to the non-treatment half to keep its liquid contents from freezing. The power for both air supplies was jointly measured, resulting in an artificially high and atypical aeration rate. Because of the unrepresentative nature of the measurements made during Period C, Period B aeration efficiency values were used to determine power requirements for Period C. Period B results were also used to determine power requirements for Period A when electrical energy demand data were not collected.

An analysis was made to determine the accuracy of the aeration power consumption measurements made. It was determined that the oxygen transfer efficiency at Helena was better than design. The static tube aeration system design oxygen transfer efficiency was 8.1 percent at an air flow rate of 0.68 m^3/min/tube (24 scfm/tube). The measured Period B transfer efficiency was 9.2 percent at an air flow rate of 0.37 m^3/min/tube (13.1 scfm/tube). The reason for the better measured oxygen transfer efficiency may have been due to operation at a lower air flow rate per tube.

The aeration blowers performed about as expected. Design power consumption was 0.91 kW/m^3/min (32.1 kW/1,000 cfm), which was within 3.6 percent of the measured power consumption of 0.94 kW/m^3/min (33.3 kW/1,000 cfm). Based on this good correlation between design and measured values for both power consumption and oxygen transfer efficiency, it appears that the measured watthour meter and oxygen uptake rate readings during Period B are reasonable. Thus, the resulting aeration efficiency of 1.16 kg O_2/kWh (1.90 lb/wire hp-hr) will be used for calculating aeration power requirements in the remainder of the report.

Aeration efficiency could possibly be substantially increased by substituting fine bubble diffusers for the static mixer aerators employed in the Helena aeration basin. In a recent study conducted for the U.S. EPA, Houck and Boon (3) estimated the average field aeration effficiency of 16 fine bubble, ceramic dome diffuser, municipal wastewater treatment installations surveyed in the United Kingdom, United States, and the Netherlands to be 1.48 kg O_2/kWh (2.43 lb/wire hp-hr). This figure is 28 percent higher than the 1.16 kg O_2/kWh (1.90 lb/wire hp-hr) value used in this report.

All of the dome diffuser installations surveyed by Houck and Boon were treating primary effluent, most of them in a plug flow hydraulic regime. Aeration efficiency in the front end of these aeration basins was invariably adversely affected by low alpha values, due to undergraded surfactants, and external dome biofouling, due to localized high volumetric organic loadings and low D. O., which resulted in coarse bubbling. Neither circumstance would be expected to be much of a factor in the front end of an ABF aeration basin. Most of the influent surfactants are probably adsorbed or degraded and part of the primary effluent oxygen demand satisfied during passage through the

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bio-cell. Therefore, if anything, the field aeration efficiency of dome diffusers in ABF service may be higher than the average value reported by Houck and Boon.

Total System Energy

Total electrical energy required to operate the Helena ABF system varied for each period. Using the mean bio-cell pumping power requirement of 38 kWh/m^3 (145 kWh/mil gal) and an aeration efficiency of 1.16 kg O_2/kWh (1.90 lb/wire hp-hr), the total system energy requirement for each period was determined as shown in Table 24. The total energy required was similar during Periods A and B at 1,701 and 1,615 kWh/day, respectively, and about 20 percent lower during Period C at 1,298 kWh/day. The unit energy requirement followed, accordingly, at 5.10, 4.73, and 4.36 kWh/1,000 m^3 (19.3, 17.9, and 16.5 kWh/mil gal) for Periods A, B, and C, respectively.

Unit power consumption was comparable for Periods B and C, but higher during Period A due to bio-cell direct recirculation. Direct recirculation flow was provided during Period A so that tower hydraulic loadings would be similar throughout the project. Also, this procedure was similar to the system operation that was practiced prior to the start of the project. However, it is believed that no adverse effects on system operation, maintenance, or performance would have occurred if direct recirculation had been omitted during Period A. If omitted, Period A unit energy demand would have been 3.62 kWh/1,000 m^3 (13.7 kWh/mil gal), which would have been the lowest energy

TABLE 24. TOTAL ABF SYSTEM ELECTRICAL ENERGY DEMAND

Parameter		Period A	Period B	Period C
Bio-Cell Pumping				
Wastewater flow	(mgd)	3.67	3.75	3.27
Return sludge flow	(mgd)	1.77	1.97	1.97
Recirculation flow	(mgd)	3.39	0	0
Total flow pumped	(mgd)	8.83	5.72	5.24
Power utilized	(kWh/day)	1,280	829	760
Aeration Oxygenation				
Aeration basin OUR	(mg/l/hr)	25.5	41.2	55.4
Aeration basin OUR	(lb/day)	1,372	2,217	1,496
Bio-cell effluent D.O.	(mg/l)	7.4	6.6	5.3
Aeratin basin D.O.	(mg/l)	3.4	2.3	2.6
Blower O_2 transferred	(lb/day)	1,077	2,012	1,378
Blower power utilized	(kWh/day)	421	786	538
Total System				
Power utilized	(kWh/day)	1,701	1,615	1,298
	(kWh/mil gal)	19.3	17.9	16.5

mgd x 3,785 = m^3/day; lb/day x 0.454 = kg/day; kWh/mil gal x 0.264 = kWh/1,000 m^3

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demand for all three periods. This illustrates that an ABF system may be more energy efficient at loadings less than the design loading. In fact, at low enough bio-cell loadings, it may be possible to satisfactorily operate the system without short-term aeration and its associated cost, as practiced at Helena (standards met during the summer months) before short-term aeration was installed.

One of the claims made for the ABF process is that it requires significantly less energy than a conventional activated sludge system, yet achieves similar treatment efficiencies. Calculated power consumption values are summarized in Table 25 for comparison.

The energy requirements for all of the ABF system cases calculated were less than for the conventional activated sludge system case. Also, the potential for an even greater reduction in energy requirements for the ABF process exists. The energy requirements calculated for Periods A, B, and C assume gravity return sludge flow to the recirculation wet-well, as existed at Helena. Provision of separate return sludge pumping would decrease the pumping energy requirement by 10 percent. Also, the analysis assumes a bio- cell media depth of 4.3 m (14 ft). Reducing media depth to 2.1 m (7 ft) would decrease pumping energy requirements another 22 percent.

The calculated energy requirements shown in Table 25 are for secondary treatment only and do not include energy associated with primary treatment, sludge processing, or other treatment units. Additionally, many assumptions and conditions unique to Helena were included in the analysis. It is important that the qualifications of the data be understood prior to its use in developing energy consumption comparisons between different treatment alternatives.

In Table 25, the pumping energy requirement is identical for Periods A, B, and C and the total system energy requirement greater for Periods B and C. The reason for the higher system energy needs for Periods B and C over Period A is additional oxygen requirements in the aeration basin. Supposedly, based on the data evaluation presented herein, even greater aeration oxygen demand and energy consumption would occur at higher bio-cell loadings. The overall evaluation indicates that the ABF process offers potential for energy savings compared to the conventional activated sludge process.

SLUDGE WASTING REQUIREMENTS

Two approaches concerning sludge production and associated wasting requirements are presented in this study. One develops the data using methods common to conventional sludge yield and cell growth theory and concentrates on volatile suspended solids (VSS) production. The purpose of this evaluation is to develop sludge growth rates for the ABF process that can be compared to growth rates for other treatment processes. The second approach presents data that develop total suspended solids (TSS) wasting requirements and reflect the practical aspects of sludge handling needs associated with the process.

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TABLE 25. POWER REQUIREMENTS FOR FOUR COMPARATIVE SECONDARY TREATMENT SYSTEMS

Parameter	ABF Process Configuration Period A	ABF Process Configuration Period B	ABF Process Configuration Period C	Conventional Activated Sludge
Assumptions Wastewater Flow = 3 mgd Return Sludge Flow = 1.5 mgd Bio-Cell Direct Recirculation Flow = 0 Primary Effluent BOD_5 = 150 mg/1 Secondary Effluent Soluble BOD_5 = 10 mg/1 MLVSS = 2,750 mg/1 Periods A and B; 3,000 mg/1 Period C				
Bio-Cell				
Organic loading (lb BOD_5/day 1,000 ft^3)	87	175	175	N/A
Pumping energy (kWh/day)	653	653	653	33
Aeration Basin				
System F_R/M loading* [kg $(BOD_5)_R$/day/kg MLVSS]	0.57	0.57	1.04	-
Oxygen requirement† [kg O_2/kg $(BOD_5)_R$]	0.45	0.63	0.47	1.2
Aeration energy§ (kWh/day)	560	803	607	1,651
Total Secondary System				
Energy consumption (kWh/day)	1,213	1,456	1,260	1,689
Percent less than activated sludge	28	14	25	0

mgd x 3,785 = m^3/day; lb BOD_5/day/1,000 ft^3 x 0.016 = kg/day/m^3; wire hp-hr x 0.746 = kWh

*System F_R/M loading is defined as the mass of BOD_5 removed across the bio-cell and aeration basin per day (based on P.E. BOD_5 minus S.E. soluble BOD_5) divided by the mass of MLVSS in the aeration basin.

†From Figure 5.

§Assume 1.9 lb O_2/wire hp-hr and contributions of oxygen from the bio-cell in Periods A, B, and C = 150, 161, and 101 lb/day, respectively.

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Sludge Yield Evaluation

A sludge yield evaluation estimates the mass of new cells grown, expressed in terms of mass of VSS produced per mass of BOD_5 removed. Eckenfelder (4) presented equations for determining solids production in an activated sludge system, with the following equation used when suspended solids are present in the influent wastewater:

$$\text{kg VSS wasted/day} = f + (a)\ [\text{kg } (BOD_5)_R/\text{day}] + (b)(\text{kg MLVSS})$$

In this equation, "a" represents the fraction of BOD_5 converted to new cells, "b" is the fraction of VSS under aeration that are oxidized each day, and "f" is the fraction of influent VSS that are non-biodegradable and pass through the process relatively unchanged. In order to determine the mass of sludge grown by the process, the mass of non-biodegradable influent VSS must be determined, which is difficult. Therefore, the above equation is often simplified to combine non-degradable and degradable VSS as follows:

$$\text{kg VSS wasted/day} = (a)[\text{kg } (BOD_5)_R/\text{day}] + (b)(\text{kg MLVSS})$$

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These coefficients can be determined experimentally from a graph of net growth rate (kg VSS wasted/day/kg MLVSS under aeration) versus substrate removal rate [kg $(BOD_5)_R$/day/kg MLVSS], as illustrated in Figure 9. Theoretically, the slope of the line of best fit is the sludge growth coefficient, a, and the intercept the endogenous coefficient, b. Typical values for the sludge growth coefficient for domestic wastewater are 0.45 to 0.65 kg VSS/kg $(BOD_5)_R$ and for the endogenous coefficient -0.05 to -0.15 day^{-1} (4)(5).

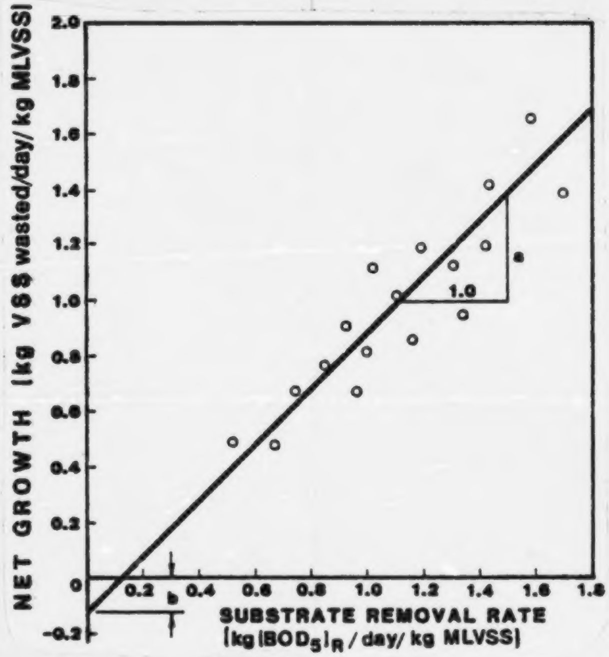

Figure 9. Theoretical determination of sludge growth rate.

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In calculating sludge yield for the ABF system at Helena, solids in the final clarifier effluent were included in sludge production totals. Also, the changes in the mass of suspended solids in the system were taken into account. Changes in the mass of fixed growth solids were not able to be determined and were excluded from the analysis. Sludge production data, including non-biodegradable VSS in the process influent, are graphically illustrated in Figure 10 for the three research periods. The slope of the line of best fit, or sludge yield coefficient, is 0.41 kg VSS/kg $(BOD_5)_R$. This value is reasonably close to literature values for activated sludge. However, the endogenous coefficient is significantly larger at 0.41 day^{-1}, compared to the theoretical value of -0.05 to -0.15 day^{-1}.

The variance in the results for sludge yield was thought to have been due to inclusion of the non-biodegradable VSS in the primary clarifier effluent in the analysis. An approach was made to exclude these solids by assuming that 40 percent of the VSS in the primary clarifier effluent was non-biodegradable (5). The graph developed with this modification is shown in Figure 11. Sludge yield represented by the line of best fit is 0.18 kg VSS/kg$(BOD_5)_R$, and the endogenous coefficient is 0.38 day^{-1}. These results appear to deviate even further from the literature reported values. Apparently, both of these approaches to data analysis for the ABF process do not lend themselves to activated sludge theory. The deviation may be due in part to the undetermined mass of fixed growth sludge on the bio-cell media. However, other factors such as limited data points or temperature effects may also have contributed to the deviation in the results from expected ranges of values.

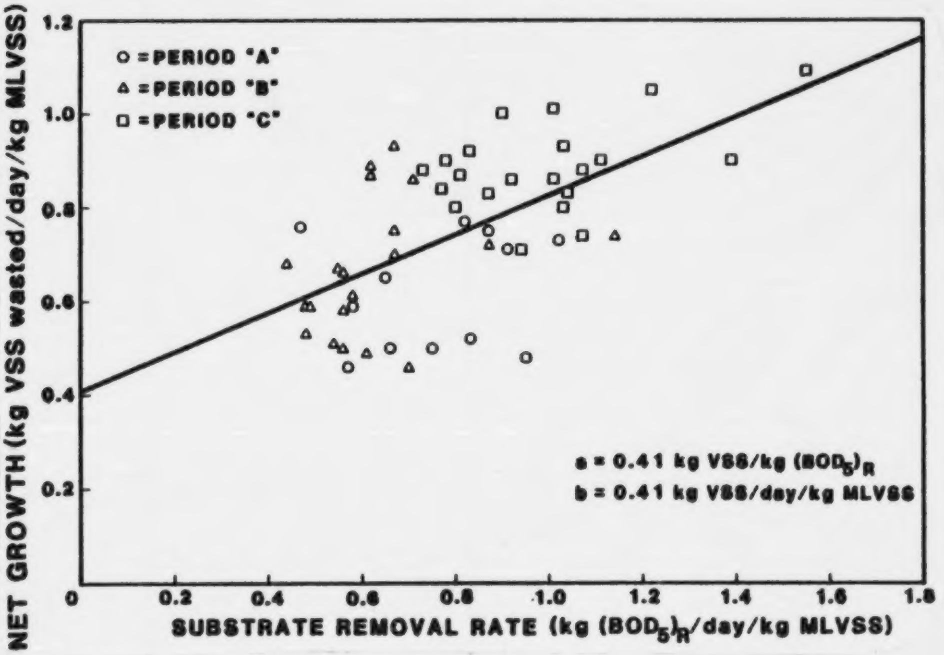

Figure 10. Sludge growth rate including non-biodegradable VSS in influent.

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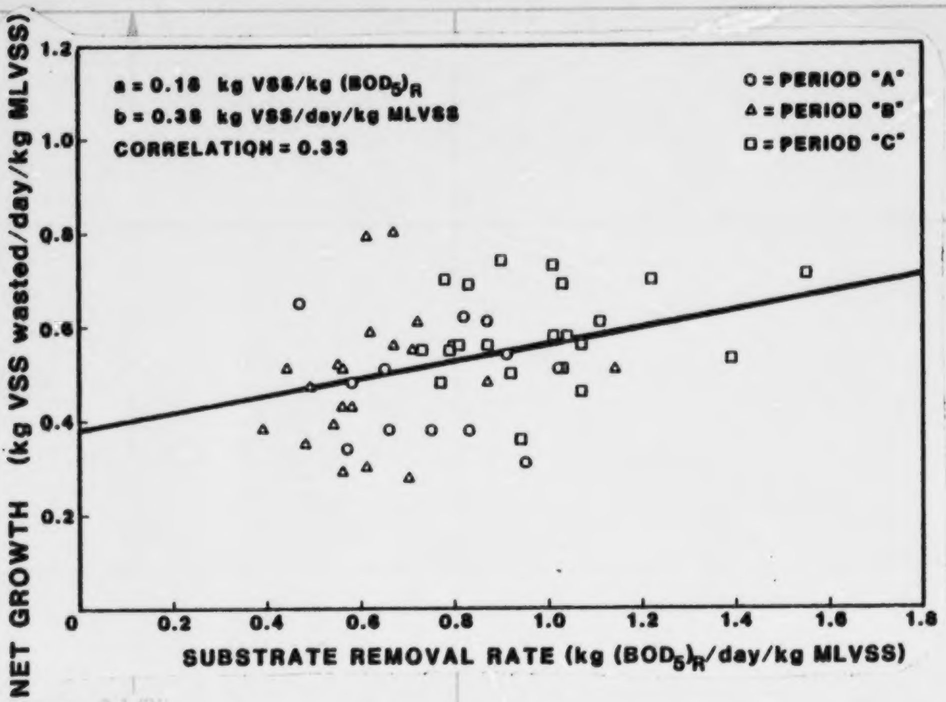

Figure 11. Sludge growth rate excluding non-biodegradable VSS in influent.

Another approach to developing the sludge yield coefficient is empirical in nature and compares sludge production [kg TSS/kg $(BOD_5)_R$] with the primary effluent solids to BOD_5 ratio, i.e., kg TSS/kg BOD_5 (6). Weekly average results for all three data collection periods are shown in Figure 12. As the primary effluent TSS:BOD_5 ratio increased, the sludge production rate [kg TSS wasted/kg $(BOD_5)_R$] also increased. In this analysis, the y-intercept of the line of best fit was used to determine sludge yield. Theoretically, if the primary effluent TSS:BOD_5 ratio was zero (y-intercept), then all of the BOD_5 would be soluble. From Figure 12, the sludge production rate at the y-intercept is 0.62 kg TSS/kg $(BOD_5)_R$ and would comprise only new sludge grown. Assuming the new sludge growth is 90-percent volatile sludge, the sludge yield coefficient is 0.56 kg VSS/kg $(BOD_5)_R$. This value compares favorably with typical activated sludge values.

A fourth approach to determining sludge yield was also examined (7). The emperical equation employed in this approach for determining total mass of TSS produced is as follows:

TSS produced = Biological solids production + Influent inert solids +
Influent non-biodegradable VSS

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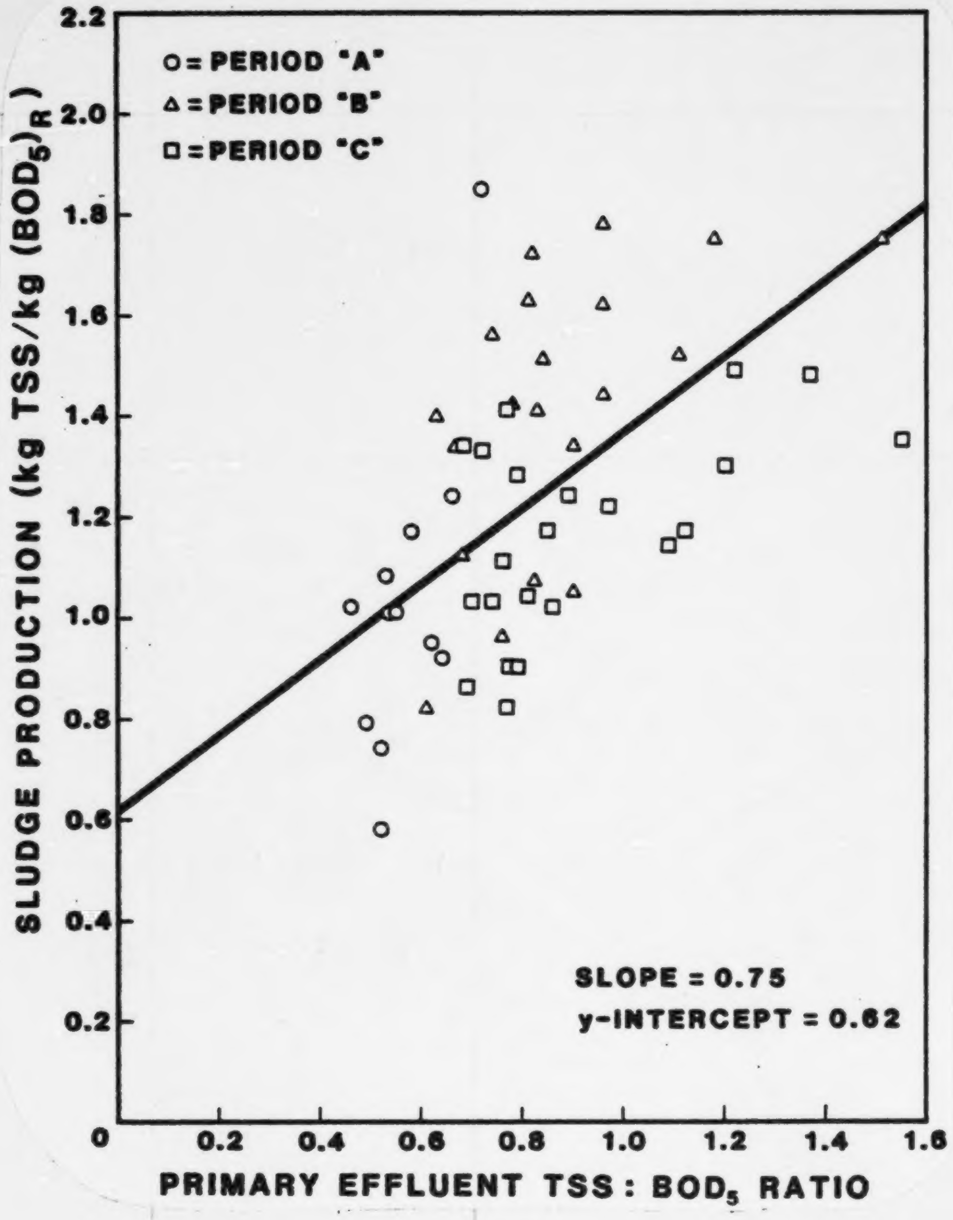

Figure 12. Sludge growth rate using primary effluent TSS:BOD_5 ratio.

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In this equation, the mass of TSS produced and the mass of influent inert solids can be determined from analytical test results and appropriate flow data. Influent non-biodegradable VSS are estimated as those influent VSS that exert a COD but not a BOD:

$$\text{Influent non-biodegradable VSS} = \text{Inf. VSS } 1 - \left[\frac{\text{Inf.BOD}_5 - \text{Inf.Sol. BOD}_5}{\text{Inf.COD} - \text{Inf.Sol. COD}}\right]$$

From the values that are measured, the biological solids production can be calculated as follows:

Biological solids production = TSS produced - Influent inert solids - Influent non-biodegradable VSS

From this equation, biological solids production was developed as mass of TSS grown per day. This value was converted to mass of VSS grown by multiplying by the VSS:TSS ratio of the new cells (assumed to be 0.90). The sludge yield coefficient was obtained by dividing the mass of biological VSS grown by the mass of $(BOD_5)_R$.

Using average data results for each period, as shown in Appendix B, and with the following data collection considerations, the sludge yield coefficient for each period was determined. The resulting sludge growth rates for Periods A, B, and C were 0.59, 0.59, and 0.34 kg VSS/kg $(BOD_5)_R$, respectively.

1. The primary effluent VSS:TSS ratio was 0.79 for all periods.
2. The soluble BOD_5 and COD values were used with the corresponding total BOD_5 and COD values (both analyzed 2 days/wk) to calculate influent non-biodegradable VSS.
3. The primary effluent BOD_5 value (analyzed 7 days/wk) and secondary effluent soluble BOD_5 value (analyzed 2 days/ wk) were used to calculate $(BOD_5)_R$.

A summary of the calculated values for sludge yield using all of the described approaches is shown in Table 26. Support for an exact sludge yield coefficient was not believed to be adequately developed from the data available. As such, no conclusion can be drawn as to whether an ABF process generates more or less sludge than other treatment processes.

Secondary System Sludge Wasting Evaluation

The practical considerations for evaluating secondary system sludge wasting requirements necessitates determining the total mass of secondary sludge that must be directed to the sludge handling and disposal facilities. This value for each operating period is shown in Table 27. A partial explanation for the relatively high secondary sludge wasting rates may have been "pass-through" solids, which comprised a large portion of the sludge wasted.

TABLE 26. SLUDGE GROWTH RATE AS CALCULATED BY FOUR ANALYTICAL APPROACHES

Analytical Approach	Sludge Growth Rate [kg VSS/kg $(BOD_5)_R$]
1. Theoretical (including non-biodegradable VSS in influent)	0.41
2. Theoretical (excluding non-biodegradable VSS in influent)	0.38
3. Emperical (relative to influent TSS:BOD_5 ratio)	0.56
4. Emperical (relative to calculated biological solids production)	
Period A	0.59
Period B	0.59
Period C	0.34

TABLE 27. SECONDARY SYSTEM TOTAL SLUDGE WASTING REQUIREMENTS FOR PERIODS A, B, AND C

Period	Secondary Sludge Wasted* (lb TSS/day)
A	3,383
B	4,362
C	2,960

lb x 0.454 = kg

*Excludes effluent suspended solids.

The large variation in solids production may have been due to the fact that biological systems inherently have variable sludge production rates from season to season (8).

The portion of solids that "passed through" the secondary system was calculated for each operational period and presented in Table 28. This calculation was based on the empirical approach for determining biological solids production presented earlier in this report. As shown, the portion of the solids that "passed through" the system (influent inert solids plus influent non-biodegradable volatile solids) comprised from 25 to 60 percent of the secondary sludge wasted during the various periods. In order for the ABF

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process to perform satisfactorily, the sludge treatment and disposal facilities must be of sufficient capacity to handle all of the secondary sludge wasted, whether biologically generated or "passed through" the system.

As shown in Table 28, secondary sludge wasted for the three periods was highly variable, ranging from an average 0.95 kg TSS/kg $(BOD_5)_R$ in Period A to an average 1.30 kg TSS/kg $(BOD_5)_R$ in Period B. Secondary sludge system wasting requirements were expected to be somewhat higher during Period B than in Period A because of the higher process loadings imposed in Period B, but the magnitude of the increase was suprising. At the same time, the highest system loading condition of Period C produced a lower secondary sludge wasting rate than Period B. Based on these results, the City of Helena continued the Period B mode of operation subsequent to completion of formal data collection for the project to verify or repute secondary sludge wasted values for Period B. These 16 wk of post-project data are presented in Appendix B. The resulting average secondary sludge wasted value was 1.86 kg TSS/kg $(BOD_5)_R$, which was even higher than the original Period B value. These relatively high secondary system sludge wasted values may have been due, in part, to the mode of operation implemented, but other circumstances also existed.

TABLE 28. INFLUENT INERT SOLIDS, INFLUENT NON-BIODEGRADABLE VOLATILE SOLIDS, AND BIOLOGICAL SOLIDS WASTED

Parameters	Period A	Period B	Period C
TSS Wasted* (lb/day)	3,383	4,362	2,960
BOD_5 Removed† (lb/day)	3,551	3,346	2,727
[kg TSS/kg $(BOD_5)_R$]	0.95	1.30	1.09
Influent Inert Solids			
(lb TSS/day)	469	729	624
[kg TSS/kg $(BOD_5)_R$]	0.13	0.22	0.23
(% of total)	14	17	21
Influent Non-Biodegradable Volatile Solids			
(lb VSS/day)	476	1,152	1,174
[kg VSS/kg $(BOD_5)_R$]	0.13	0.34	0.43
(% of total)	14	26	40
Biological Solids Wasted			
(lb VSS/day)	2,438	2,481	1,162
[kg VSS/kg $(BOD_5)_R$]	0.69	0.74	0.43
(% of total)	72	57	39

lb x 0.454 = kg

* Excludes effluent suspended solids.

†Total BOD_5 removed across secondary system.

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Period B and post-project data collection were both conducted during the months of March through July. Other investigations of sludge production at activated sludge plants have shown that the sludge production ratio typically varies from one period of the year to another (8). Periods of high and low sludge production typically lasted for several months, and some plants showed recurring high sludge production during each spring. No definite cause was isolated, but environmental changes were suspected. High sludge production was also measured in plants with variable seasonal organic loadings, with changes in the operating environment again suspected as the cause. It appears that the variable sludge production ratios at Helena are consistent with trends observed at other plants. The important fact is that variable sludge production measured at Helena is not unusual. Sludge treatment and disposal facilities must be sized to adequately handle these shorter-term peaks, as well as the long-term average.

Secondary system sludge wasting production data at Helena indicate that its secondary sludge treatment and disposal facilities should be sized to handle about 1.1 kg TSS/kg $(BOD_5)_R$, on the average, and should be capable of handling significantly higher wasting rates for several months at a time. Also, it appears that sludge production was not directly related to system loading in the range evaluated, but was more dependent upon other undetermined factors. The sludge production rate was dependent upon biological solids generated, as well as solids which "passed through" the process. Both components were highly variable making a straightforward design approach difficult to develop. Sludge handling is a high priority item for a well-operated ABF system and should be considered as such during system design and operation.

SYSTEM PERFORMANCE

The data collection schedule for the research project was formulated to document the performance of the ABF system under different loading conditions, including system design loadings. A major consideration was to operate at each loading condition for a sufficient length of time to insure adequate biological system acclimation to a changed loading condition and to verify system stability at that condition. These considerations formed the basis for selecting the length of time for the data collection periods, while at the same time keeping within the overall project time period. The final data collection program selected included three different plant loading conditions, two of which coincided with cold weather and one with warm weather.

Loadings

For municipal systems, Neptune Microfloc (2) recommends a bio-cell loading of 3.2 kg/day/m^3 (200 lb/day/1,000 ft^3) and an aeration basin loading to achieve a system F_A/M ratio of 1.43 kg BOD$_5$ applied to the bio-cell in the primary effluent/day/kg MLVSS in the aeration basin (based on an MLVSS concentration of 3,000 mg/l). During the research project, the Helena ABF facility was loaded at three different conditions by removing from service portions of the system. The approach was to operate at the lowest loading condition initially and the highest loading condition at the end of the project. Using this approach, it was felt that the plant operators would gain familiarity with the research project and system operation when the system was less affected by operational considerations.

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A summary of the process loadings for Periods A, B, and C, as compared to Neptune Microfloc's recommended loadings, is shown in Table 29. In Period A, the bio-cell and aeration basin were loaded at about 50 percent of design. In

TABLE 29. ABF PROCESS LOADING CONDITIONS EVALUATED

Parameter	Period A	Period B	Period C
Wastewater Flow (mgd)	3.67	3.75	3.27
Primary Effluent BOD_5 (mg/l)	130	128	124
Bio-Cell			
Organic loading (lb BOD_5/day/1,000 ft^3)			
Actual	93	186	157
N.M.F.* recommendation	200	200	200
Percent of design	47	93	79
Hydraulic loading (gpm/ft^2)			
Actual	2.0	2.59	2.37
N.M.F. recommendation	1.5-5.5	1.5-5.5	1.5-5.5
Aeration Basin			
System F_A/M loading (kg P.E. BOD_5/day/kg MLVSS)			
Actual	0.81	0.65	1.07
N.M.F. recommendation	1.43	1.43	1.43
Percent of design	57	45	75
Wastewater detention time (min.)			
Actual	106	103	59
N.M.F. recommendation	44	43	42
MLVSS (mg/l)			
Actual	2,195	2,735	2,820
N.M.F. recommendation	3,000	3,000	3,000
Aeration volume (gal)			
Actual	269,300	269,300	134,600
N.M.F. recommendation	111,300	111,900	94,500
Percent of design	242	241	142
Secondary Clarifier			
Surface loading rate (gpd/ft^2)			
Actual	415	424	370
N.M.F. recommendation	600	600	600
Percent of design	69	71	62

*N.M.F. = Neptune Microfloc

mgd x 3,785 = m^3/day; lb BOD_5/day/1,000 ft^3 x 0.016 = kg/day/m^3; gpm/ft^2 x 0.679 = l/sec/m^2; gpd/ft^2 x 0.041 = m^3/day/m^2

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Period B, half of the ABF tower was removed from service, with the aeration basin remaining at Period A loadings. In Period C, half of the aeration basin was also removed from service, but the influent flow and organic concentration slightly decreased. The effect was a lower bio-cell loading during Period C than in Period B. For all periods, both final clarifiers were in service with surface loading rates near 16 $m^3/day/m^2$ (400 gpd/ft^2).

During the project, all wastewater flow was treated in the ABF system, including normal domestic wastewater plus infiltration/inflow (I/I). During the latter part of Period A and the beginning of Period B, a substantial volume of I/I was received. This wastewater flow condition is illustrated in Figure 13 where weekly average flow rates for the research project are shown. However, this period of substantial I/I was relatively short and did not significantly affect the overall process evaluation.

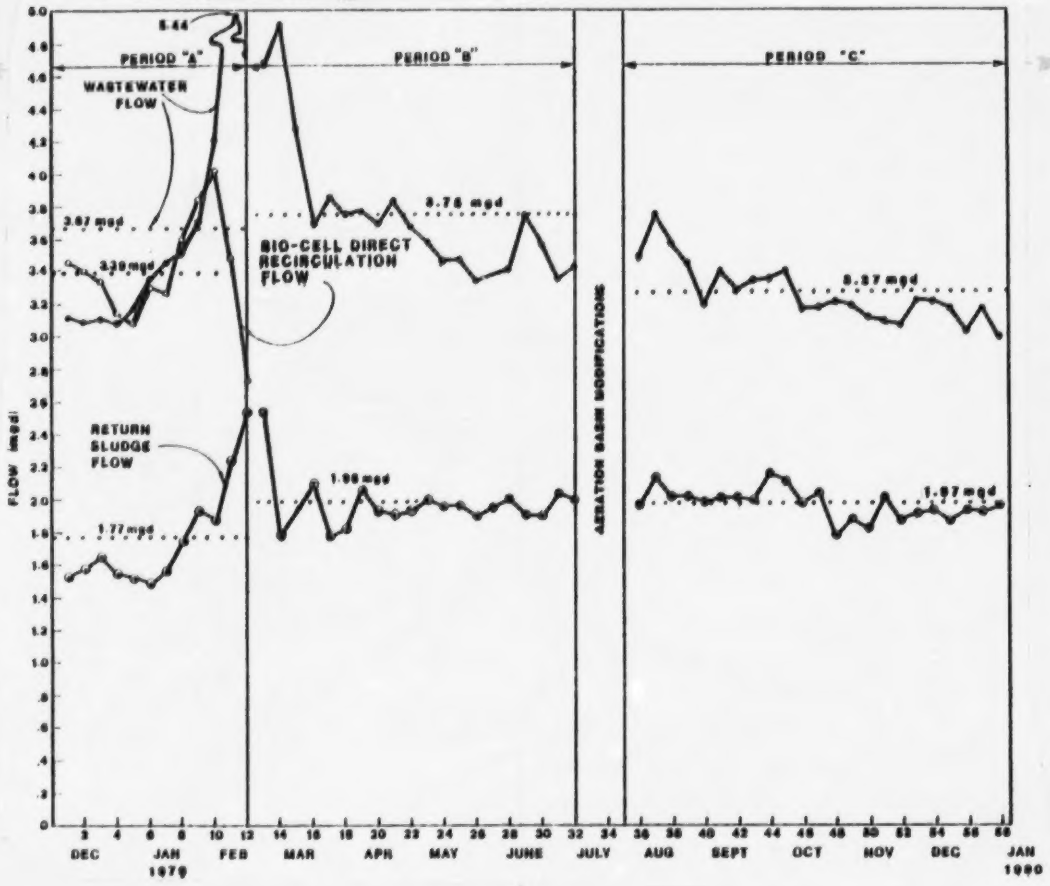

Figure 13. Weekly-average system flow rates during Periods A, B, and C.
Note: mgd x 3,785 = m^3/day

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Also shown in Figure 13 are the weekly average return sludge and bio-cell direct recirculation flow rates. Bio-cell recirculation was provided during Period A while both towers were in service. No direct recirculation was utilized during Periods B or C while one-half of the tower was removed from service. The return sludge flow rate was generally maintained at 50 to 60 percent of the wastewater flow rate.

During the project, waste sludge from the ABF system was recycled to the primary clarifier. The volume recycled was only 1 percent of the volume of wastewater entering the primary clarifier and did not significantly affect its performance or the hydraulic and organic loadings on the bio-cell. Also, secondary waste sludge recycle was the only recycle flow back through the plant. No sidestream flows were recycled from the sludge handling system or any plant units.

Temperature Effects

The Helena ABF system was originally designed without short-term aeration, and plant performance was satisfactory during the warmer months but unsatisfactory during the colder months of the year. Based on a potential similar impact of temperature on process performance for Helena's modified system with short-term aeration, temperatures were closely monitored during the project. Also, wastewater temperatures were monitored to determine the magnitude of the temperature drop through the bio-cell during the coldest period of the year.

The raw wastewater, primary effluent, secondary effluent, and ambient temperatures were measured daily, and weekly averages are depicted in Figure 14. During the warmer months, the raw wastewater and primary effluent temperatures were similar and reached 19°C. The secondary effluent temperature typically increased 1°C. During the colder months, the primary effluent temperature generally was 1°C lower than the raw wastewater temperature, except when the raw wastewater temperature reached its lowest level of 10°C. At that time, the primary effluent temperature was also 10°C. The secondary effluent temperature varied from 8°C in the winter to 20°C in the summer. The colder temperatures occurred during the end of Period A, beginning of Period B, and end of Period C. Plant effluent quality during these times was equal to or better than the mean effluent quality for the respective operational period; thus, the effect on performance of the lower temperatures recorded was minimal.

The temperature drop between the primary and secondary clarifiers occurred during the winter due to wastewater cascade over the primary clarifier weir and mixed liquor distribution through the ABF bio-cell. The secondary effluent temperature was generally 2 to 3°C less than the primary effluent temperature. Of this decrease, from 1 to 2°C occurred through the bio-cell and the remainder by the cascading effect over the primary clarifier weir. The greatest temperature drops were recorded during the most extreme weather conditions in Helena, including the coldest winter on record (i.e., December 1978 and January and February 1979) and when bio-cell direct recirculation was implemented. This drop in temperature did not significantly affect the performance of the process, nor did it adversely affect plant operation and maintenance.

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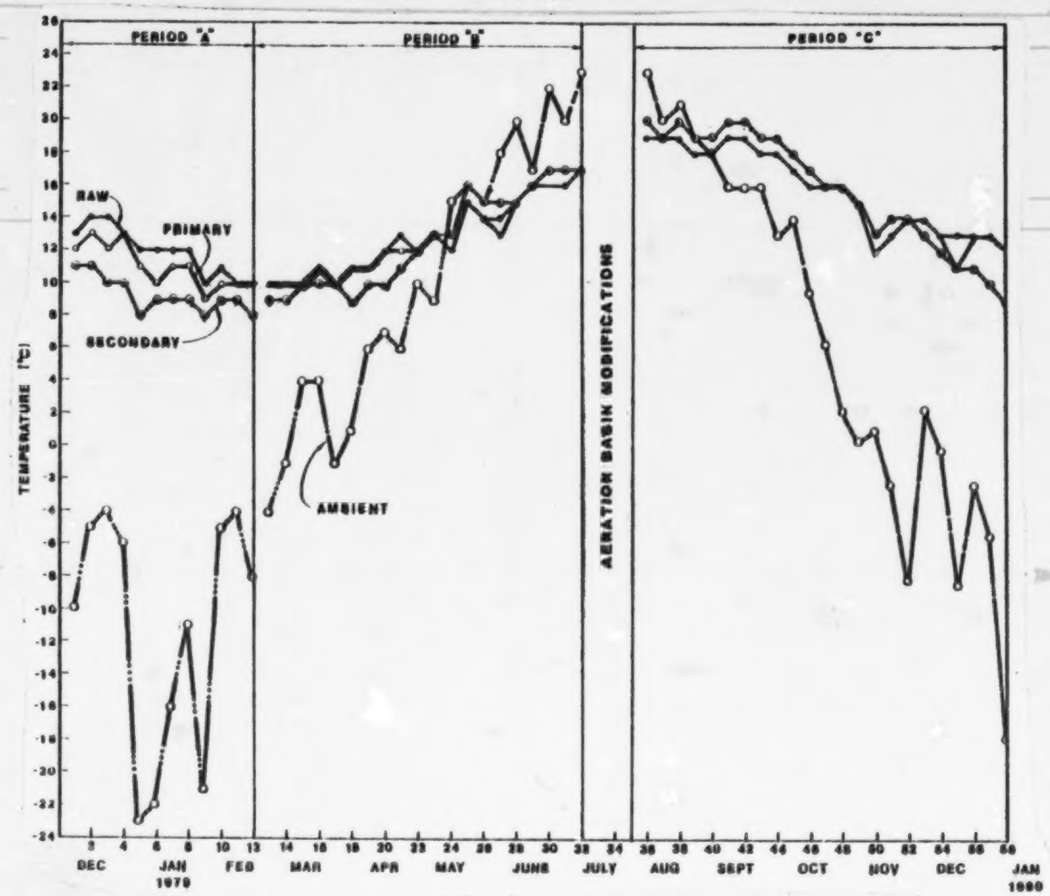

Figure 14. Weekly-average liquid and ambient temperatures during Periods A, B, and C.

Effluent Quality

The ABF project evaluation was based on the system's ability to meet federally-defined secondary treatment standards. Weekly- and monthly-average concentrations were not to exceed 45 and 30 mg/l, respectively, for both BOD_5 and TSS. Further, the overall plant was to achieve 85 percent removal of the raw wastewater BOD_5 and TSS concentrations on a monthly basis. In addition, the evaluation was based on the system's ability to meet Neptune Microfloc's design criteria of 20 mg/l BOD_5 and TSS concentrations in the process effluent. The evaluation also monitored the system's capability to nitrify, although nitrification was not a project objective or a process design criteria. At no time during the project did the system nitrify at the high loading conditions evaluated.

The evaluation consisted of three process loading conditions, during which cold weather constraints were experienced for a sufficient period of time to verify system stability at each condition. Every effort was made to

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optimize process control so that system design capabilities could be effectively determined. As discussed earlier, process control was not fully optimized until the end of Period B when MCRT management was instituted for sludge wasting control.

Optimum sludge wasting control resulted in less fluctuations in the MLSS concentration. Less-than-optimum control did not significantly affect performance at the lowest process loading condition during Period A. Performance did deteriorate during Period B to a greater extent than expected when one-half of the bio-cell was removed from service. During Period C when one-half of the aeration basin was also removed from service, optimum process control was exercised and effluent quality was felt to fully reflect process capabilities. Subsequent to formal research data collection, the Helena plant staff operated their ABF system at Period B loadings for 16 wk, in the same season of the year and with optimum process control. This post-research data, called Period B', indicated better process performance and is felt to more accurately reflect process capabilities at Period B loadings, especially for TSS removal.

A summary of process loadings, influent quality, effluent quality, and removal efficiencies for Period A, B, C, and B' is presented in Table 30. Weekly-average data for all periods are presented in Appendix B. In general, effluent quality decreased as process loading increased. Secondary BOD_5 removal decreased from 89 percent in Period A to 81 percent in Period C, and secondary TSS removal decreased from 86 percent to 80 percent for the same periods. Final effluent BOD_5 increased from 14 to 24 mg/l and TSS from 10 to 22 mg/l from Period A to Period C, respectively. Periods B and B' final effluent BOD_5's at 21 mg/l and 19 mg/l, respectively, were similar and between values achieved in Periods A and C. Period B final effluent TSS were higher than expected at 27 mg/l because of operational problems as earlier discussed. Period B' final effluent TSS averaged 17 mg/l and are felt to better reflect results representative of system capabilities at Period B loadings.

The general deterioration in effluent quality and process capability as loading increased is also illustrated in the secondary effluent soluble BOD_5 and COD results, also shown in Table 30. Final effluent soluble BOD_5 for Periods A and B was similar, and for Period C somewhat higher. Soluble COD increased slightly for each subsequent period. This trend was expected when unit process capability was evaluated and provides further support for the rationale that optimum process control existed and plant operation did not negatively influence system performance.

The primary objective of the research project was to determine if the ABF process could meet the requirements of the federally-defined secondary treatment standards at loadings near design conditions. A portion of the secondary treatment standard requires that weekly-average BOD_5 and TSS concentrations not exceed 45 mg/l. Weekly-average values for secondary effluent BOD_5 and TSS are shown, respectively, in Figures 15 and 16 for Periods A, B, and C. The individual weeks' values show that the weekly standard for BOD_5 was consistently met. The TSS standard was violated once during Period B, for operations reasons discussed earlier. It should be noted that neither the BOD_5 or TSS standard was violated during Period B'.

TABLE 30. PROCESS LOADINGS, INFLUENT AND EFFLUENT QUALITIES AND REMOVAL EFFICIENCIES

Parameter	Period A	Period B	Period C	Post-Research Period B'
Bio-Cell				
Organic loading ($lb BOD_5/day/1,000 ft^3$)	93	186	157	142
Percent of design	47	93	79	71
Aeration Basin				
Detention time (min)	106	103	59	103
Percent of design	242	241	142	316
Flow				
Wastewater (mgd)	3.67	3.75	3.27	3.26
Return (mgd)	1.77	1.97	1.97	1.84
Recirculation (mgd)	3.39	0	0	0
BOD_5				
Raw (mg/1)	175	148	152	164
Primary (mg/1)	130	128	124	112
Secondary (mg/1)	14	21	24	19
Secondary removal (%)	89.2	83.6	80.6	83.0
Overall removal (%)	92.0	85.8	84.2	88.4
COD				
Raw (mg/1)	380	386	437	--
Primary (mg/1)	249	279	276	--
Secondary (mg/1)	66	93	89	--
Secondary removal (%)	73.5	66.7	67.8	--
Overall removal (%)	82.6	75.9	79.6	--
TSS				
Raw (mg/1)	130	194	214	196
Primary (mg/1)	73	111	109	102
Secondary (mg/1)	10	27	22	17
Secondary removal (%)	86.3	75.7	79.8	83.3
Overall removal (%)	92.3	86.1	89.7	91.3
Soluble BOD_5				
Primary (mg/1)	68	56	63	--
Secondary (mg/1)	9.8	7.8	12	--
Soluble COD				
Primary (mg/1)	136	138	152	--
Secondary (mg/1)	53	61	70	--

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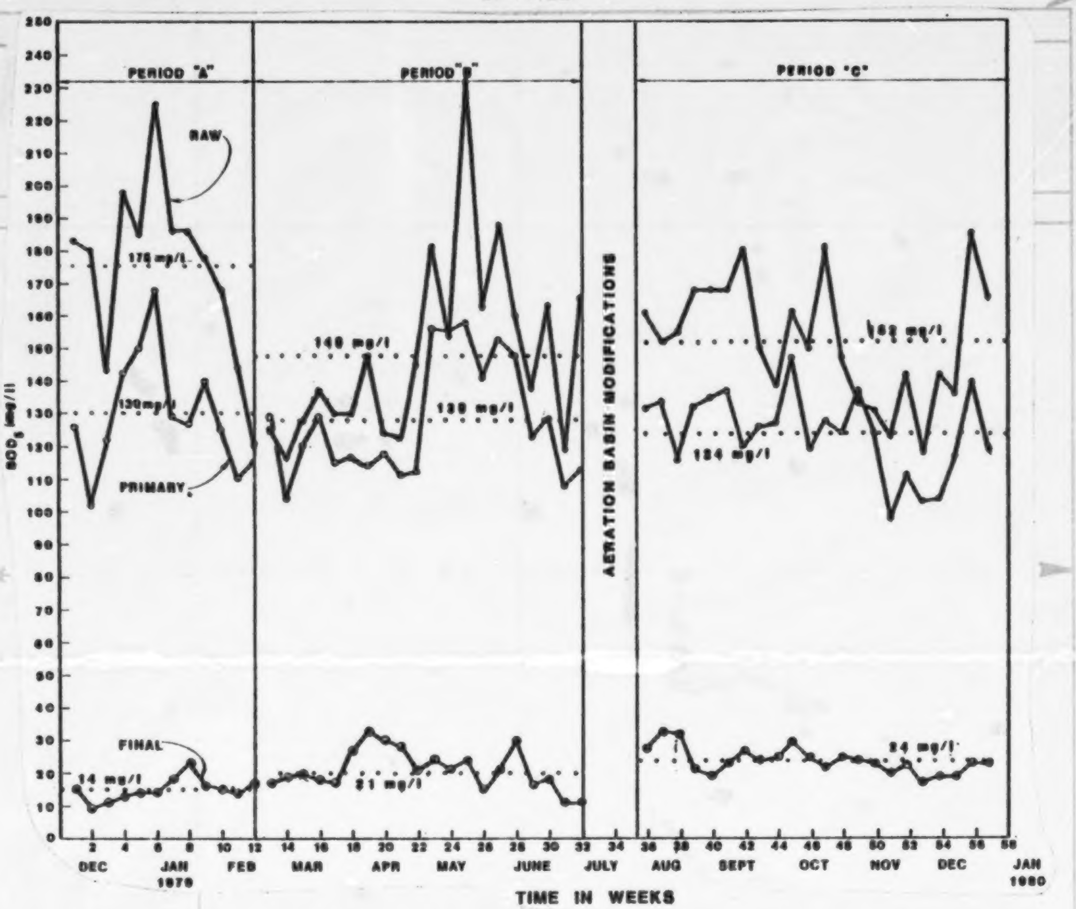

Figure 15. Weekly-average system BOD_5 concentrations during Periods A, B, and C.

Another secondary treatment requirement is meeting maximum monthly-average BOD_5 and TSS concentrations of 30 mg/l. Compliance with this standard was evaluated by comparing 4-wk moving average values for BOD_5 and TSS with the 30-mg/l limit. This comparison is shown in Figure 17. The 4-wk moving average values for secondary effluent BOD_5 and TSS concentrations were consistantly less than 30 mg/l in Periods A and C. In Period B, the effluent BOD_5 was equal to or less than 30 mg/l, but the effluent TSS concentration exceeded the limit five times. As discussed, these violations were felt to be due to operational practices and not limitations of the ABF process. No violations occurred in Period B'.

A third secondary treatment requirement specifies monthly-average total plant removal efficiencies of 85 percent or greater for BOD_5 and TSS. Compliance with the 85-percent removal requirement was evaluated by comparing this value to the 4-wk moving averages of raw wastewater to secondary effluent BOD_5 and TSS removal efficiencies. These results are shown in Figure 18. In Period A, greater than 90-percent removal of both BOD_5 and TSS occurred.

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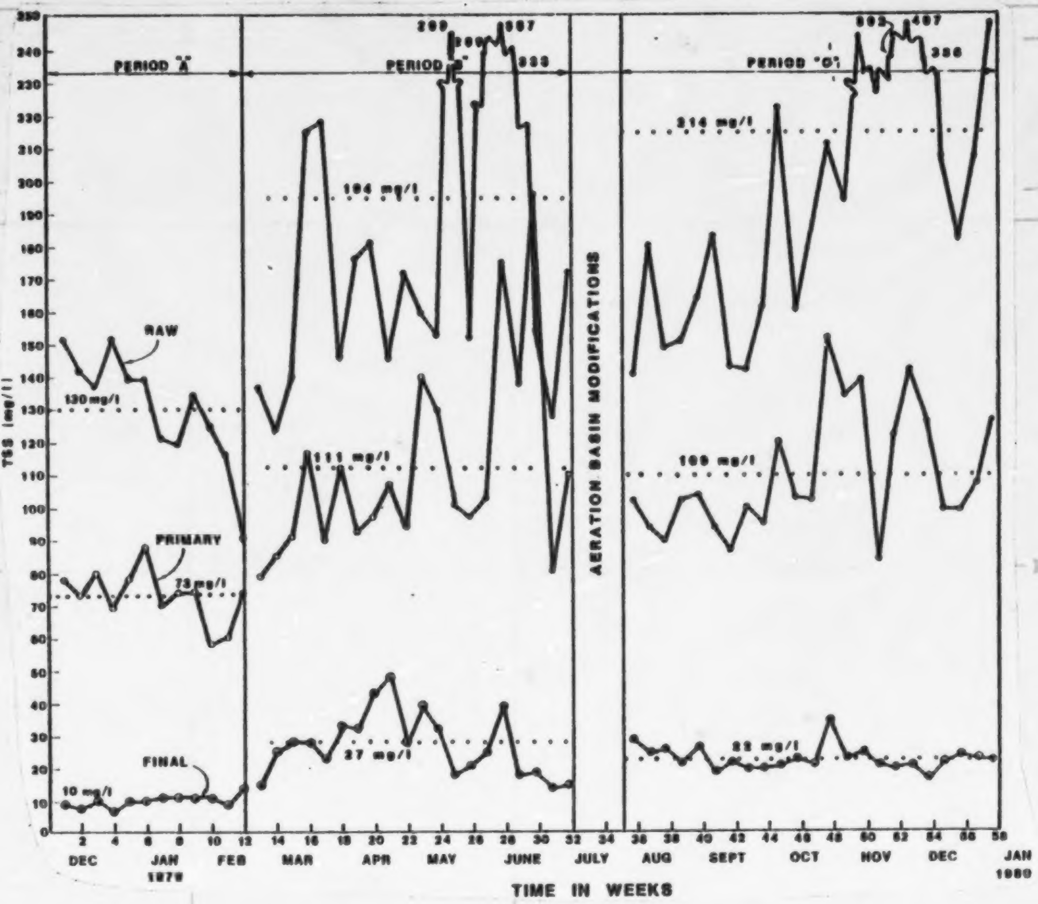

Figure 16. Weekly-average system TSS concentrations during Periods A, B, and C.

In Period B, a wide fluctuation occurred in the removal efficiencies of both parameters. When the effluent concentrations were high, as shown in Figure 17, both the BOD_5 and TSS removal efficiencies were less than 85 percent. Later in Period B, the removal efficiencies were above 85 percent and near 90 percent. These higher removal efficiencies are felt to be more reflective of process design capabilities. This is further supported by the fact that the average plant removal efficiencies during Period B' were 88 percent for BOD_5 and 91 percent for TSS.

During Period C, BOD_5 removal efficiencies were generally lower and TSS removal efficiencies generally higher than 85 percent. At the start of Period C, both BOD_5 and TSS removal efficiencies were less than 85 percent, which may be attributed to process startup, relatively low influent wastewater strength, and system acclimation to a changed loading condition. Subsequently, TSS removal efficiencies stayed above 85 percent. BOD_5 removal efficiencies increased to above 85 percent shortly after startup, but then decreased to less than 85 percent for 10 consecutive wk. Near the end of

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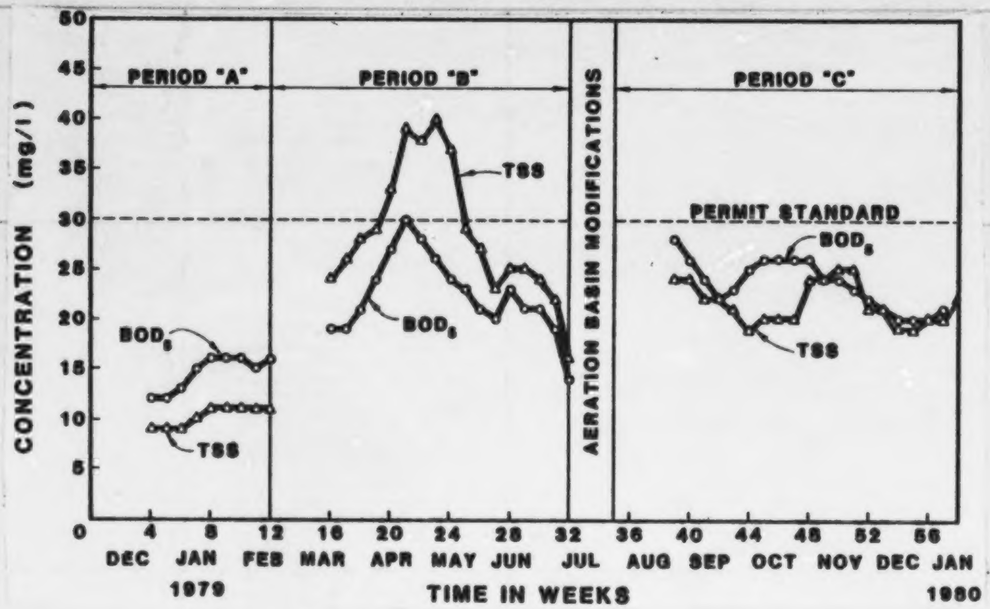

Figure 17. Four-week moving average final effluent BOD_5 and TSS concentrations.

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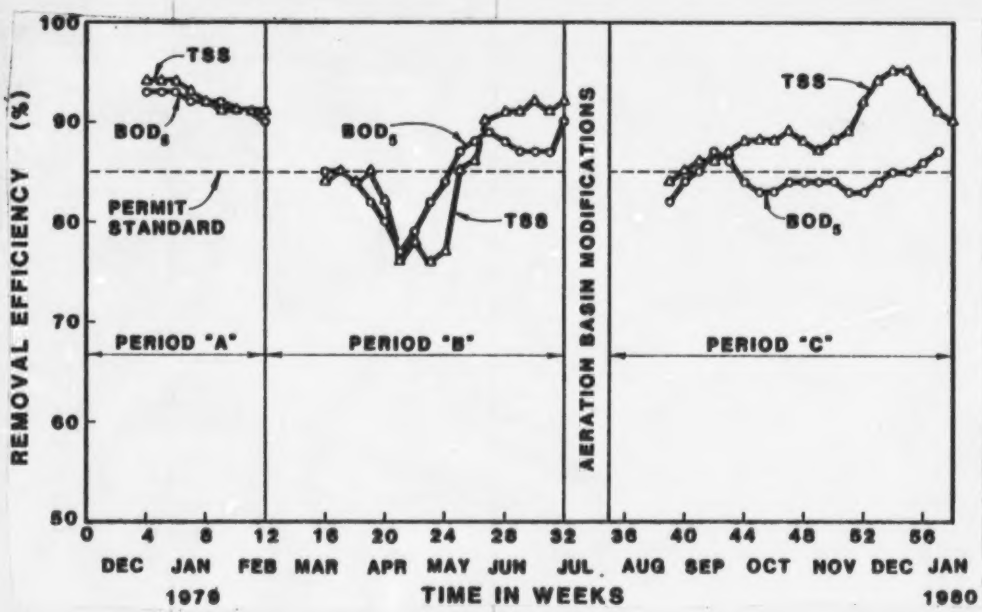

Figure 18. Four-week moving average BOD_5 and TSS plant removal efficiencies.

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Period C, BOD_5 removal efficiencies were greater than 85 percent despite the fact that the wastewater and ambient temperatures were coldest at this time. The increase in BOD_5 removal efficiencies toward the end of Period C was due primarily to an increase in influent wastewater BOD_5 concentrations. Final effluent BOD_5 concentrations were quite consistent at 20 to 25 mg/l.

It appears that the ABF process can meet all secondary treatment standards at Period A and Period B loadings if operational practices are optimized. Standards can also be met at Period C loadings, except for BOD_5 removal efficiency when the wastewater BOD_5 concentration is relatively weak. Another characteristic evident throughout the project was excellent process stability. Stability was achieved through attainment of relatively rapid sludge settling rates throughout the project, as presented earlier. As such, no problems were experienced with excess solids loss from the final clarifiers. The most stable process performance occurred in Periods C and B' when optimum process control was exercised.

ABF system effluent quality results were also compared to Neptune Microfloc's design criteria of 20 mg/l for BOD_5 and TSS (1). These criteria were achieved at Period A and Period B' loadings, but were not consistently achieved at Period C loadings. It appears that process loadings capable of achieving 20-mg/l discharge criteria are less than imposed during Period C and more in line with the loadings of Period B'.

The Helena ABF research project included an evaluation of three loading conditions, two of which involved a larger aeration basin size and one a smaller size. An attempt was made to determine the relative effectiveness of the short-term aeration basin size on process performance and define the optimum design interrelationship between the two. To aid in this determination, historical plant records can be used to evaluate system performance without short-term aeration. Historically, plant peformance was satisfactory during warm weather and unsatisfactory during cold weather months, as shown in Figure 19. Process organic loading was similar to values measured during Period A, with the bio-cell organic loading around 1.44 kg BOD_5/day/m^3 (90 lb/day/1,000 ft^3). Both ABF towers were in service, and no short-term aeration was provided. The total volume of "aeration" media was 1,218 m^3 (43,000 ft^3), where "aeration" media refers to facilities whose function it is to convert soluble and colloidal organic material to settleable suspended solids, in this case the bio-cell only.

During the project, short-term aeration was evaluated as part of the ABF process. Total "aeration" volume during Period A was 2,237 m^3 (79,000 ft^3), and plant effluent quality was excellent. In Periods B and B', the total "aeration" volume was 1,628 m^3 (57,500 ft^3) and system performance was very satisfactory. In Period C, the total "aeration" volume was 1,119 m^3 (39,500 ft^3) and the discharge effluent quality was satisfactory. Thus, Period C performance was better than historical performance despite the fact that the total "aeration" volume was less during Period C. This illustrates the beneficial effect of short-term aeration on ABF process performance. A similar beneficial effect was noted when comparing results for Periods B and B' with Period C results. A definate trend for better system performance occurred at similar bio-cell organic loadings when a larger aeration basin was used in Periods B and B'.

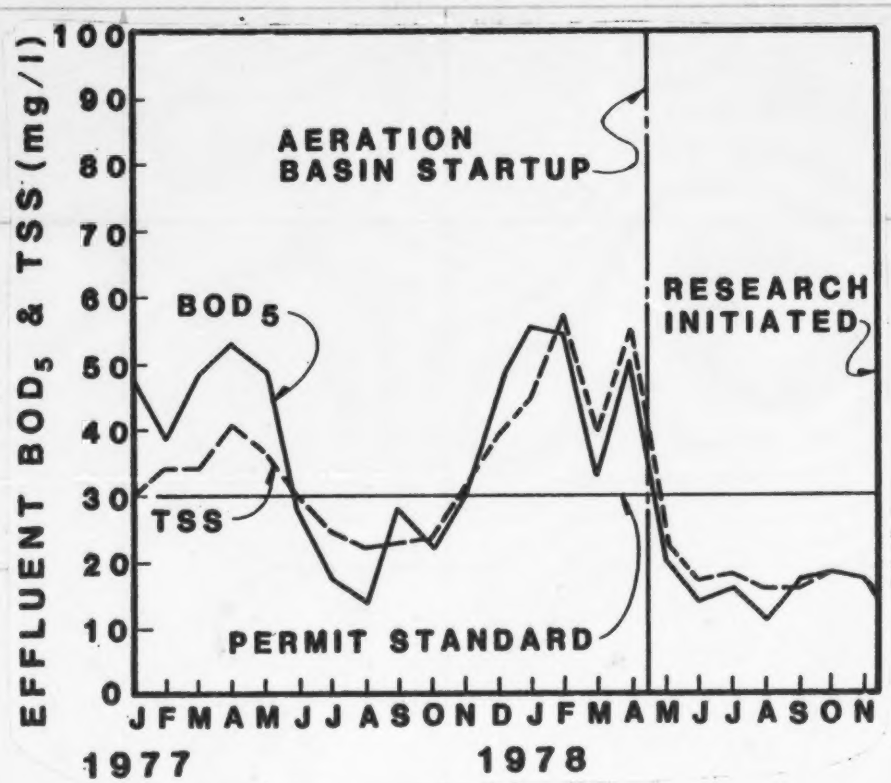

Figure 19. Helena effluent BOD_5 and TSS concentrations prior to research project.

Neptune Microfloc's (1) recommended process design is for a bio-cell organic loading of 3.2 kg/day/m^3 (200 lb/day/1,000 ft^3) and an aeration basin nominal detention time typically less than 1 hr. These and higher process loadings could not be evaluated during the research project; thus, the sytem was not operated to a "failure" condition. However, it was felt that process performance at Periods C and B' loadings could be used to analyze system design capabilities.

In Figure 20, effluent total BOD_5 is plotted against Periods C and B' F_A/M loadings. During this time frame, the bio-cell organic loading averaged 2.4 kg BOD_5/day/m^3 (150 lb/day/1,000 ft^3). As shown, effluent total BOD_5 increased as system F_A/M loading increased. The linear regression line of best fit indicates a poor correlation, but general trends of the data are indicated. Also shown in Figure 20 is the 95-percent confidence interval for the data. A strict interpretation of the graph suggests that an effluent BOD_5 of 30 mg/l could be met with a 95-percent confidence factor at a system F_A/M loading of 1.0 kg BOD_5/day/kg MLVSS and a bio-cell organic loading of 2.4 kg BOD_5/day/m^3 (150 lb/day/1,000 ft^3).

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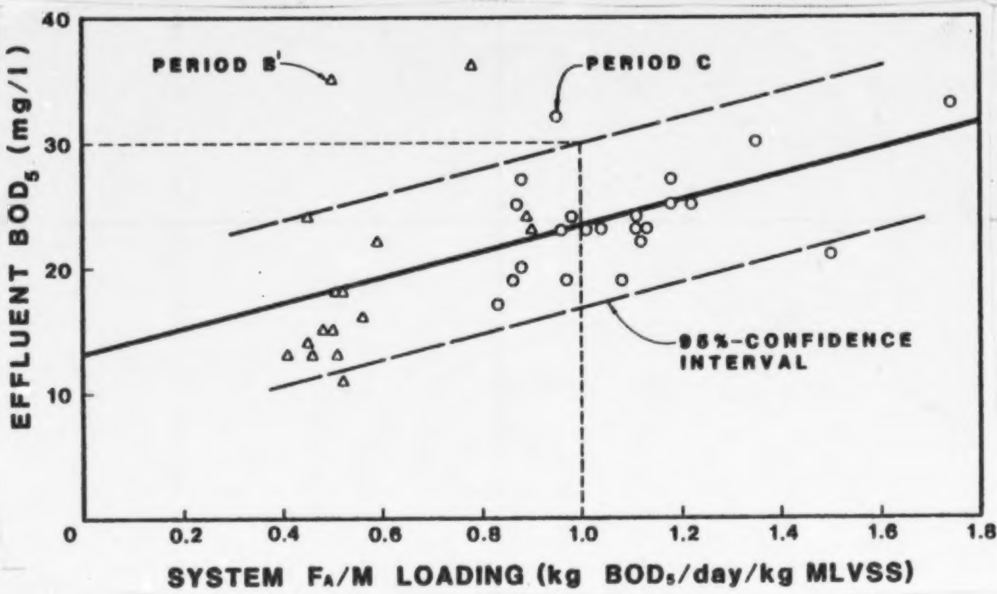

Figure 20. Effluent BOD$_5$ as a function of system F$_A$/M loading during Periods C and B'.

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The average bio-cell organic loading in Periods C and B' was 75 percent of Neptune Microfloc's recommended design loading. It is reasonable to assume that a higher bio-cell organic loading would necessitate a lower system F$_A$/M loading, i.e., a larger aeration basin. Based on these data, it is recommended that design engineers of ABF systems consider using a larger aeration basin size (i.e., lower system F$_A$/M loadings), similar to that evaluated in Periods B and B'. By using this design approach, the full benefits of the ABF process, including stability and energy savings, can be realized while consistently achieving permit compliance.

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APPENDIX A

DAILY PROCESS CONTROL TESTING, RECORDING, AND CALCULATION SHEETS

Item	Page
1. Daily Process Control Tests Sheet	70
2. Helena ABF Suspended Growth Mass Worksheet	71
3. Helena ABF Research Daily Control Calculations Sheets	72
4. Column Information for Daily Control Calculations Sheets	73
5. Sample Helena ABF Research Daily Control Calculations Sheets	78

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DAILY PROCESS CONTROL TESTS
CITY OF HELENA ABF RESEARCH

SETTLEOMETER TEST INFO. **DAY** ______ **DATE** ________

TIME __________

TIME	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		

TIME __________

TIME	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		

TIME __________

TIME	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		

MISC INFO:

COMPOSITE SPIN

ATC __________
RSC __________
XSC __________

ELECTRICAL ENERGY

BLOWERS __________ KWH
RECIRC PUMPS __________ KWH
WASTE PUMPS __________ KWH

$$SSC = \frac{(1000)(ATC)}{SSV}$$

WASTING INFO. **MULTIPLICATION FACTOR** __________

TIME BEGAN	TIME ENDED	TOTALIZER BEGIN	TOTALIZER END	TOTALIZER DIFFERENCE	GALLONS	% XSC BEGAN	% XSC ENDED	% AVER XSC	SLUDGE UNITS WASTED GAL × %
				TOTAL				TOTAL	

ADDITIONAL INFO.

TIME	ATC %	RSC %	CSC %	DTB_1 FT	DTB_2 FT	$TURB_1$ NTU	$TURB_2$ NTU	SSC_5 %	SSC_{30} %	SSC_{60} %	OUR MG/L/HR	AIR TEMP °C
AVG												

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HELENA ABF Date ____________

SUSPENDED GROWTH MASS WORKSHEET

Obejctive MCRT ________ Estimated ESU ________ Waste periods/day __________

TIME	ATC	AVERAGE ATC	CSC	AVERAGE CSC	CUMULATIVE XSC

$$\begin{aligned} TSU &= (ATC \times 0.269) + (ATC \times 0.038) + (CSC \times 0.76) \\ &= (0.307 \times ATC) + (0.76 \times CSC) \end{aligned}$$

$$XSU = \left(\frac{TSU}{MCRT} - ESU\right) \div \text{Waste periods/day} = \text{Amount to be wasted}$$

PERIOD 1
TIME
____

TSU = (0.307 x _________) + (0.76 x _______) = _______________
XSU = (_________ - _______) ÷ ___________ = ______________

PERIOD 2
TIME
____

TSU = (0.307 x _________) + (0.76 x _______) = _______________
XSU = (_________ - _______) ÷ ___________ = ______________

PERIOD 3
TIME
____

TSU = (0.307 x _________) + (0.76 x _______) = _______________
XSU = (_________ - _______) ÷ ___________ = ______________

PERIOD 4
TIME
____

TSU = (0.307 x _________) + (0.76 x _______) = _______________
XSU = (_________ - _______) ÷ ___________ = ______________

FINAL PERIOD
TIME
____

TSU = (0.307 x _________) + (0.76 x _______) = _______________
XSU = (_________ - _______) - __________ = ______________

Cumulative XSU
Final XSU Required

____
Required Total XSU

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HELENA ABF RESEARCH
DAILY CONTROL CALCULATIONS
FROM ________ THRU ________

AV = ________ MG CV = ________ MG DOC = ________ FT CSA = ________ FT² BIO-CELL VOLUME = ________ FT³ BIO-CELL SURFACE AREA = ________ FT²

PAGE 1 of 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			21	22	23
DAY	DATE	ATC %	RSC %	CSC %	DTB FT	TURB NTU	FLOW MGD	RSF MGD	RSPP %	SCRF MGD	SCRPP %	TPSC MGD	SCHL GPD/FT²	ASU MG x S	CSU MG x S	TVSC MG	SCSU MG x S	TSU MG x S	SDR ASU:SCSU:CSU			ESU MG x S	ZSU MG x S	WSU MG x S
FRI																					1			
SAT																					1			
SUN																					1			
MON																					1			
TUES																					1			
WED																					1			
THUR																					1			
WEEKLY	AVG																				1			
FRI																					1			
SAT																					1			
SUN																					1			
MON																					1			
TUES																					1			
WED																					1			
THUR																					1			
WEEKLY	AVG																				1			
FRI																					1			
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MON																					1			
TUES																					1			
WED																					1			
THUR																					1			
WEEKLY	AVG																				1			
FRI																					1			
SAT																					1			
SUN																					1			
MON																					1			
TUES																					1			
WED																					1			
THUR																					1			
WEEKLY	AVG																				1			
																					1			
4-WEEK	AVG																				1			

HELENA ABF RESEARCH
DAILY CONTROL CALCULATIONS
FROM ________ THRU ________

AV = ________ MG CV = ________ MG DOC = ________ FT CSA = ________ FT² BIO-CELL VOLUME = ________ FT³ BIO-CELL SURFACE AREA = ________ FT²

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		24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
DAY	DATE	MCRT DAYS	RSU MG x S	SDV_A MG	SDV_{SC} MG	SDV_C MG	TSV MG	CYCLES	$SDV_A \div ATC$ MG x S	CBL UNITS/FT²	OFR GPD/FT²	SSC_0 %	SSC_{30} %	SSC_{60} %	SVI ML/GM	RSP %	OUR MG/L/HR	WASTE GAL/DAY	RECIRC [illegible]	AERATION [illegible]	WASTE [illegible]	
FRI																						
SAT																						
SUN																						
MON																						
TUES																						
WED																						
THUR																						
WEEKLY	AVG																					
FRI																						
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4-WEEK	AVG																					

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EPA-287 (Cin.)
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COLUMN INFORMATION FOR DAILY CONTROL CALCULATIONS SHEETS

Column	Symbol	Symbol Meaning	Explanation
1	DAY	Self Explanatory	
2	DATE	Self Explanatory	
3	ATC	Aeration Tank Concentration	Average of values recorded during the day on the daily data sheet.
4	RSC	Return Sludge Concentration	Average of values recorded during the day on the daily data sheet.
5	CSC	Clarifier Sludge Concentration	Average concentration of sludge within the clarifier. Average of values recorded during the day on the daily data sheet.
6	DTB	Depth to Sludge Blanket	Average of values for both clarifiers recorded during the day on the daily data sheet.
7	TURB	Final Clarifier Turbidity	Average of values for both clarifiers recorded during the day on the daily data sheet.
8	FLOW	Average Daily Wastewter Flow	Wastewater flow in mil gal for a given 24-hr time period (e.g., 8:00 A.M. to 8:00 A.M.).
9	RSF	Return Sludge Flow	Daily average return sludge flow rate in mgd. (Note: Time period for determining this rate should be the same as the time period used for determining daily wastewater flow rate, e.g., 8:00 A.M. to 8:00 A.M.).
10	RSFP	Return Sludge Flow Percentage	Percentage expression of the ratio of the volume of return sludge flow to the volume of raw wastewater. $\text{RSFP} = \text{RSF} \div \text{FLOW} \times 100\%$ $= \text{COL } 9 \div \text{COL } 8 \times 100\%$
11	BCRF	Bio-Cell Direct Recirculation Flow	Daily total flow in mgd from the bio-cell underdrain directly to the recirculation wet well. (Note: Time period for determining this flow should be the same as for determining the average daily wastewater flow.

EPA-287 (Cin.)
(4-76)

COLUMN INFORMATION FOR DAILY CONTROL CALCULATIONS SHEETS

Column	Symbol	Symbol Meaning	Explanation
12	BCRFP	Bio-Cell Direct Recirculation Flow Percentage	Percentage expression of the ratio of the volume of direct bio-cell recirculation to the volume of raw wastewater. BCRFP = BCRF ÷ FLOW x 100% = Col 11 ÷ Col 8 x 100%
13	TFBC	Total Flow to the Bio-Cell	Total volume of liquid pumped to the bio-cell. TFBC = FLOW + RSF + BCRF = Col 8 + Col 9 + Col 11
14	BCHL	Bio-Cell Hydraulic Load	Volume of liquid pumped to the bio-cell per unit area of bio-cell in operation. $\frac{\text{Col 13} \times 695}{\text{Bio-Cell Surface Area}}$
15	ASU	Aerator Sludge Units	Total aeration tank volume in mil gal (AV) multiplied times the daily average ATC. ASU = AV x ATC = AV x Col 3
16	CSU	Clarifier Sludge Units	Volume of the clarifier in mil gal (CV) times the average clarifier sludge concentration (CSC). CSU = CV x CSC = CV x Col 5
17	TVBC	Total Volume in the Bio-Cell	Volume of mixed liquor in the bio-cell and associated appurtenances. TVBC - volume in tower, volume in underdrain (0.011 mil gal), volume in recirculation wet well (0.012 mil gal), and volume in tower piping (0.008 mil gal). Tower Vol. = $(0.43)\left(\frac{\text{Media Vol-ft}^3}{\text{Col 13} \times 695}\right)^{0.85}\left(\frac{\text{Col 13} \times 695}{1{,}000{,}000}\right)$ = mil gal TVBC = Tower Vol. + 0.031
18	BCSU	Bio-Cell Sludge Units	Volume of mixed liquor in bio-cell x ATC. BCSU = Col 3 x Col 17

COLUMN INFORMATION FOR DAILY CONTROL CALCULATIONS SHEETS

Column	Symbol	Symbol Meaning	Explanation
19	TSU	Total Sludge Units	Sum of the aerator sludge units, bio-cell sludge units, and clarifier sludge units. $\text{TSU} = \text{ASU} + \text{BCSU} + \text{CSU}$ $= \text{Col } 15 + \text{Col } 16 + \text{Col } 18$
20	SDR	Solids Distribution Ratio	Ratio of the mass of solids in the aeration tank to mass of sludge in the bio-cell to mass of sludge in the final clarifiers. $\text{SDR} = \frac{\text{ASU}}{\text{CSU}} : \frac{\text{BCSU}}{\text{CSU}} : 1$
21	ESU	Effluent Sludge Units	Quantity of sludge lost in the effluent each day. Effluent suspended solids (TSS) times FLOW (Col 8) divided by Ratio of suspended solids to percent solids by centrifuge. Ratio = correlation of mixed liquor suspended solids tests to centrifuge ATC values. $\text{ESU} = \frac{(\text{TSS})\ (\text{FLOW})}{\text{Ratio}}$
22	XSU	Intentionally Wasted Sludge Units	Mass of sludge intentionally wasted from the system. Use total from the daily data sheet wasting information.
23	WSU	Total Waste Sludge Units	Sum of effluent sludge units and intentionally wasted sludge units. $\text{WSU} = \text{ESU} + \text{XSU}$ $= \text{Col } 21 + \text{Col } 22$
24	MCRT	Mean Cell Residence Time	Indication of sludge age or the "mean time an average sludge cell is in residence in the system." $\text{MCRT} = \text{TSU} \div \text{WSU}$ $= \text{Col } 19 \div \text{Col } 23$

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COLUMN INFORMATION FOR DAILY CONTROL CALCULATIONS SHEETS

Column	Symbol	Symbol Meaning	Explanation
25	RSU	Return Sludge Units	Return sludge flow rate times the return sludge concentration. $\mathrm{RSU} = (\mathrm{RSF})\ (\mathrm{RSC}) = \mathrm{Col}\ 9 \times \mathrm{Col}\ 4$
26	SDT_A	Sludge Detention Time in the Aerator	Average length of time in hours a given quantity of sludge remains in the aerator. $\mathrm{SDT}_A = \frac{\mathrm{AV} \times 24}{\mathrm{TFBC} - \mathrm{BCRF}} = \frac{\mathrm{AV} \times 24}{\mathrm{Col}\ 13 - \mathrm{Col}\ 11}$
27	SDT_{BC}	Sludge Detention Time in the Bio-Cell	Indication of the length of the time in hours the suspended growth sludge spends in the bio-cell and associated appurtenances, equal to the hydraulic detention time. $\mathrm{SDT}_{BC} = \frac{\mathrm{Vol.\ in\ Bio\text{-}Cell}}{\mathrm{Pumping\ to\ Bio\text{-}Cell}} \times 24$ $\mathrm{SDT}_{BC} = \frac{\mathrm{Col}\ 17}{\mathrm{Col}\ 13} \times 24$
28	SDT_C	Sludge Detentin Time in the Clarifiers	Average length of time the sludge remains in the clarifiers during each pass around the system. $\mathrm{SDT}_c = \frac{\mathrm{CSU}}{\mathrm{RSU}} \times 24 = \frac{\mathrm{Col}\ 16}{\mathrm{Col}\ 25} \times 24$
29	TDT	Total Detention Time	Total time required for an average particle of sludge to make one complete pass through the system. $\mathrm{TDT} = \mathrm{SDT}_A + \mathrm{SDT}_{BC} + \mathrm{SDT}_C$ $\mathrm{TDT} = \mathrm{Col}\ 26 + \mathrm{Col}\ 27 + \mathrm{Col}\ 28$
30	CYCLES	Sludge Cycles per Day	Number of times the sludge cycles through the entire system during the day. $\mathrm{CYCLES} = \frac{24}{\mathrm{Col}\ 29}$

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COLUMN INFORMATION FOR DAILY CONTROL CALCULATIONS SHEETS

Column	Symbol	Symbol Meaning	Explanation
31	$SDT_A \times ATC$	"Pressure"	Indication of the amount of pressure applied to the system for the sludge to develop = Col 26 × Col 3
32	CSL	Clarifier Solids Loading	Indicates the mass loading of solids on the final clarifiers. $CSL = \frac{ATC\ (TFBC - BCRF)}{\text{Total Clarifier Surface Area (CSA)}}$ $CSL = \frac{(\text{Col } 3)\ (\text{Col } 13 - \text{Col } 11)}{CSA}$
33	OFR	Clarifier Overflow Rate	Indication of the hydraulic upflow rate in the final clarifiers. $OFR = \frac{FLOW}{CSA} = \frac{\text{Col } 8}{CSA}$
34	SSC_5	5-min Settled Sludge Concentration	Average of values from the daily process control test sheet.
35	SSC_{30}	30-min Settled Sludge Concentration	Average of values from the daily process control test sheet.
36	SSC_{60}	60-min Settled Sludge Concentration	Average of values from the daily process control test sheet.
37	SVI	Sludge Volume Index	$\frac{1{,}000{,}000}{(SSC_{30})\ (\text{Ratio of MLSS/ATC})}$
38	RSP	Return Sludge Percentage	Indication of return flow percentage that is based on a solids balance. $RSP = \frac{ATC \times 100}{RSC-ATC} = \frac{\text{Col } 3 \times 100}{\text{Col } 4 - \text{Col } 3}$
39	OUR	Oxygen Uptake Rate	Average of values from the daily process control test sheet.
40	WASTE	Waste Volume	Average of values from the daily process control test sheet.
41	RECIRC	Recirculation Power	Average of values from the daily process control test sheet.
42	AERATION	Aeration Blower Power	Average of values from the daily process control test sheet.
43	WASTE	Waste Power	Average of values from the daily process control test sheet.

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SAMPLE

HELENA ABF RESEARCH

DAILY CONTROL CALCULATIONS

FROM 12-1-78 THRU 12-28-78

AV = 0.267 MG   CV = 0.760 MG   DOC = 11.5 FT   CSA = 8836 FT²   BIO-CELL VOLUME = 43000 FT³   BIO-CELL SURFACE AREA = 3072 FT²

PAGE 1 of 2

1 DAY	2 DATE	3 ATC %	4 RSC %	5 CSC %	6 DTB FT	7 TURB NTU	8 FLOW MGD	9 RSF MGD	10 RSFP %	11 BCRF MGD	12 BCRFP %	13 TFBC MGD	14 BCHL GPM/FT²	15 ABU MG x %	16 CBU MG x %	17 TVBC MG	18 BCBU MG x %	19 TBU MG x %	20 SDR ABU	SDR BCBU	SDR CBU	21 EBU MG x %	22 XBU MG x %	23 WBU MG x %
FRI	12-1-78	3.3	11.0	1.2	7.0	3.6	3.03	1.56	0.51	3.40	1.22	7.99	1.80	0.89	0.91	0.037	0.12	1.92	09	0.1	'	(0.04)	0.34	0.38
SAT	12-2-78	3.5	10.9	0.7	7.5	3.7	3.13	1.40	0.45	3.35	1.07	7.88	1.78	0.94	0.53	0.042	0.15	1.62	1.8	0.3	'	(0.04)	0.77	0.81
SUN	12-3-78	3.7	12.1	1.5	8.5	4.1	3.21	1.41	0.44	3.56	1.10	8.16	1.85	1.00	1.14	0.042	0.16	2.30	0.9	0.1	'	0.03	0.27	0.30
MON	12-4-78	4.1	13.2	1.9	8.8	5.9	3.35	1.53	0.46	3.49	1.06	8.37	1.89	1.10	1.44	0.043	0.18	2.32	0.8	0.1	'	0.02	0.34	0.36
TUES	12-5-78	4.6	11.4	0.8	9.0	6.4	3.15	1.76	0.56	3.68	1.17	8.59	1.94	1.18	0.61	0.043	0.19	1.98	1.9	0.3	'	0.06	0.51	0.57
WED	12-6-78	4.2	11.5	1.3	8.3	4.8	3.05	1.68	0.55	3.50	1.15	8.23	1.86	1.13	0.99	0.042	0.18	2.30	1.1	0.2	'	0.04	0.55	0.59
THURS	12-7-78	4.0	11.6	0.7	8.8	4.6	2.95	1.42	0.46	3.29	1.12	7.66	1.73	1.08	0.53	0.042	0.18	1.79	2.0	0.3	'	0.04	0.62	0.66
WEEKLY	AVG	3.9	11.7	1.2	8.3	4.7	3.12	1.53	0.49	3.46	1.12	8.13	1.84	1.05	0.78	0.042	0.17	2.03	1.3	0.2	'	0.04	0.49	0.52
FRI	12-8-78	4.4	13.3	0.6	10.2	4.7	3.06	1.64	0.54	3.48	1.14	8.18	1.85	1.18	0.46	0.042	0.18	1.82	2.6	0.4	'	(0.04)	0.58	0.62
SAT	12-9-78	4.2	12.5	0.4	10.6	4.7	3.05	1.72	0.56	3.48	1.14	8.25	1.87	1.13	0.30	0.043	0.18	1.61	1.8	0.6	'	(0.04)	0.71	0.75
SUN	12-10-78	4.2	12.7	0.4	10.5	4.9	3.10	1.70	0.55	3.48	1.12	8.28	1.87	1.13	0.30	0.042	0.18	1.61	1.8	0.6	'	0.06	0.81	0.87
MON	12-11-78	4.1	12.1	0.7	9.5	9.4	3.21	1.53	0.48	3.46	1.08	8.20	1.86	1.10	0.53	0.042	0.18	1.81	2.1	0.3	'	0.05	0.85	0.90
TUES	12-12-78	3.8	10.8	0.4	9.8	7.7	3.04	1.46	0.48	3.34	1.10	7.84	1.77	1.02	0.30	0.042	0.16	1.48	1.4	0.5	'	0.01	0.75	0.76
WED	12-13-78	4.0	10.5	0.6	9.7	6.6	3.09	1.51	0.49	3.35	1.08	7.95	1.80	1.08	0.46	0.042	0.18	1.72	2.3	0.4	'	0.04	0.29	0.33
THURS	12-14-78	4.1	12.0	0.9	9.3	6.0	3.07	1.49	0.49	3.30	1.07	7.86	1.78	1.10	0.68	0.042	0.18	1.96	1.6	0.3	'	0.04	0.58	0.62
WEEKLY	AVG	4.1	12.0	0.6	9.9	6.3	3.09	1.58	0.51	3.41	1.10	8.08	1.83	1.11	0.43	0.042	0.18	1.72	1.3	0.4	'	0.04	0.65	0.69
FRI	12-15-78	4.2	12.2	0.6	10.0	6.3	2.98	1.89	0.63	3.55	1.19	8.42	1.90	1.13	0.46	0.043	0.18	1.77	2.5	0.4	'	(0.05)	0.46	0.51
SAT	12-16-78	4.0	10.9	0.8	10.0	6.1	3.05	1.66	0.54	3.31	1.09	8.02	1.81	1.08	0.61	0.042	0.18	1.87	1.8	0.3	'	(0.05)	0.75	0.80
SUN	12-17-78	3.8	10.5	0.9	10.0	5.8	3.09	1.73	0.56	3.29	1.06	8.11	1.83	1.02	0.68	0.042	0.16	1.86	1.5	0.2	'	0.05	0.71	0.76
MON	12-18-78	3.5	10.7	0.5	9.7	7.7	3.14	1.54	0.49	3.32	1.06	8.00	1.81	0.94	0.38	0.042	0.15	1.47	2.5	0.4	'	0.05	0.72	0.77
TUES	12-19-78	3.8	10.0	0.7	9.6	8.8	3.26	1.51	0.46	3.28	1.01	8.05	1.82	1.02	0.53	0.042	0.16	1.71	1.9	0.3	'	0.04	0.66	0.70
WED	12-20-78	3.4	9.9	0.6	9.8	6.2	3.16	1.62	0.51	3.34	1.06	8.12	1.84	0.91	0.46	0.042	0.14	1.51	2.0	0.3	'	0.05	0.55	0.60
THURS	12-21-78	3.4	9.5	1.4	9.2	4.8	3.10	1.63	0.53	3.29	1.06	8.02	1.81	0.91	1.06	0.042	0.14	2.11	0.9	0.1	'	0.05	0.58	0.63
WEEKLY	AVG	3.7	10.5	0.8	9.8	6.5	3.11	1.65	0.53	3.34	1.08	8.11	1.83	1.00	0.60	0.042	0.16	1.76	1.9	0.3	'	0.05	0.63	0.68
FRI	12-22-78	3.6	8.9	0.8	9.8	4.4	3.18	1.59	0.50	3.29	1.03	8.06	1.82	0.97	0.61	0.042	0.15	1.73	1.6	0.2	'	(0.06)	0.58	0.64
SAT	12-23-78	3.2	9.1	0.6	10.0	4.7	3.05	1.50	0.49	3.16	1.04	7.71	1.74	0.86	0.46	0.042	0.13	1.45	1.9	0.3	'	(0.06)	0.60	0.66
SUN	12-24-78	3.2	11.2	0.6	9.6	5.5	3.03	1.86	0.61	3.43	1.13	8.32	1.88	0.86	0.46	0.043	0.14	1.46	1.9	0.3	'	(0.05)	0.38	0.43
MON	12-25-78	3.5	7.8	0.5	8.9	4.1	2.72	1.35	0.50	2.94	1.08	7.01	1.59	0.94	0.38	0.041	0.14	1.46	2.5	0.4	'	0.02	0.55	0.57
TUES	12-26-78	3.2	10.2	0.6	9.3	4.2	3.18	1.43	0.45	3.21	1.01	7.82	1.77	0.86	0.46	0.042	0.13	1.45	1.9	0.3	'	0.05	0.46	0.51
WED	12-27-78	3.7	11.6	0.6	9.3	4.7	3.15	1.31	0.42	2.88	0.91	7.34	1.66	1.00	0.46	0.041	0.15	1.61	2.2	0.3	'	(0.05)	0.60	0.65
THURS	12-28-78	3.7	11.6	0.6	9.3	4.7	3.27	1.74	0.53	3.12	0.95	8.13	1.84	1.00	0.46	0.042	0.16	1.62	2.2	0.3	'	0.04	0.53	0.57
WEEKLY	AVG	3.4	10.0	0.6	9.5	4.6	3.08	1.54	0.50	3.15	1.03	7.77	1.76	0.93	0.47	0.042	0.14	1.54	2.0	0.3	'	0.05	0.50	0.55
																					'			
4 WEEK	AVG	3.8	11.0	0.8	9.4	5.5	3.10	1.58	0.51	3.36	1.08	8.02	1.82	1.02	0.57	0.042	0.16	1.76	2.1	0.3	'	0.04	0.57	0.61

SAMPLE

HELENA ABF RESEARCH

DAILY CONTROL CALCULATIONS

FROM 12-1-78 THRU 12-28-78

AV= 0.267 MG   CV= 0.760 MG   DOC= 11.5 FT   CSA= 8836 FT²   BIO-CELL VOLUME= 43000 FT³   BIO-CELL SURFACE AREA= 3072 FT²

PAGE 2 of 2

DAY	DATE	24 MCRT DAYS	25 RSU MG x %	26 SDT_A HR	27 SDT_{BC} HR	28 SDT_C HR	29 TDT HR	30 CYCLES	31 SDT_A x ATC HR x %	32 CEL UNITS/FT²	33 OFR GPD/FT²	34 DSC_A %	35 SSC [illegible] %	36 SSC [illegible] %	37 SVI ML/GM	38 RSP %	39 OUR MG/L/HR	40 WASTE GAL/DAY	41 RECIRC KWH/DAY	42 AERATION KWH/DAY	43 WASTE KWH/DAY	44
FRI	12-1-78	5.0	17.2	1.61	0.11	1.26	2.78	8.6	4.65	1714	363	5.4	11.1	16.2	129	43	21.2	22013				
SAT	12-2-78	2.0	15.3	1.63	0.13	0.83	2.39	10.0	5.01	1794	354	5.3	11.1	14.6	129	47	22.5	30481		156		
SUN	12-3-78	7.7	17.1	1.60	0.12	1.60	3.12	7.7	5.18	1935	363	6.6	9.9	13.1	157	44	27.4	13110	320	112		
MON	12-4-78	6.4	20.2	1.32	0.12	1.71	3.15	7.6	5.41	2264	379	5.5	9.7	13.3	166	45	28.7	20240	320	128		
TUES	12-5-78	3.5	20.1	1.31	0.12	0.73	2.16	11.1	5.76	2645	356	4.9	8.7	12.4	169	63	27.0	30235	360	140		
WED	12-6-78	3.9	19.3	1.36	0.12	1.23	2.71	8.9	5.71	2268	345	4.8	8.7	12.1	136	58	21.9	37375	400	120		
THUR	12-7-78	2.7	16.5	1.48	0.13	0.77	2.38	10.1	5.92	1978	334	6.6	9.6	12.7	149	53	22.0	39215	400	132		
WEEKLY	AVG	4.4	18.0	1.39	0.12	1.16	2.67	9.1	5.37	2054	353	5.0	9.8	13.2	145	50	24.4	27953	360	131		
FRI	12-8-78	2.9	21.8	1.37	0.12	0.51	2.00	12.0	6.03	2340	346	5.5	9.1	12.6	186	49	23.0	40825	360	132		
SAT	12-9-78	2.1	21.5	1.35	0.13	0.33	1.81	13.3	5.67	2267	345	5.0	10.0	13.4	169	53	26.3	43470	440	120		
SUN	12-10-78	1.8	21.6	1.35	0.12	0.33	1.80	13.3	5.67	2282	351	5.3	11.0	14.2	148	49	26.0	24380	560	116		
MON	12-11-78	2.0	18.5	1.36	0.12	0.69	2.17	11.1	5.58	2199	363	5.1	10.5	14.1	135	51	31.5	143060	104	168		
TUES	12-12-78	1.9	15.8	1.43	0.13	0.46	2.02	11.9	5.63	1935	366	5.2	11.0	13.5	140	56	27.2	67090	316	124	2	
WED	12-13-78	5.2	15.9	1.40	0.13	0.69	2.22	10.8	5.60	2082	350	5.5	11.9	15.6	139	62	24.3	19300		116		
THUR	12-14-78	3.2	17.9	1.42	0.13	0.91	2.33	10.3	5.82	2116	347	6.0	12.5	15.9	165	52	26.6	41975		128	4	
WEEKLY	AVG	2.7	19.0	1.38	0.13	0.59	2.05	11.8	5.69	2174	369	5.4	10.9	14.2	152	53	26.4	54300	356	129	3	
FRI	12-15-78	3.5	23.1	1.33	0.12	0.48	1.93	12.4	5.59	2315	337	6.0	12.3	15.2	129	53	22.8	40365	348	132	1	
SAT	12-16-78	2.3	18.1	1.37	0.13	0.81	2.31	10.4	4.00	2132	345	6.0	11.0	15.4	144	58	26.0	57845	360	128	2	
SUN	12-17-78	2.4	18.2	1.34	0.12	0.90	2.36	10.2	5.09	2073	350	6.4	12.2	15.2	147	57	24.9	44735	320	140	3	
MON	12-18-78	1.9	16.5	1.38	0.13	0.55	2.06	11.7	4.83	1854	355	6.6	12.6	15.5	112	49	26.0	40034	400	124	2	
TUES	12-19-78	2.4	15.1	1.35	0.13	0.84	2.32	10.3	5.13	2051	369	6.7	13.6	16.8	104	67	25.8	28860	264	184	6	
WED	12-20-78	2.5	16.0	1.35	0.12	0.69	2.16	11.1	4.59	1839	358	6.2	12.1	15.2	124	52	23.4	42402	340	128		
THUR	12-21-78	3.3	15.5	1.36	0.13	1.64	3.13	7.7	4.62	1820	351	6.3	12.8	15.4	117	57	27.2	48397	356	128	2	
WEEKLY	AVG	2.6	17.5	1.35	0.13	0.84	2.32	10.5	4.84	2012	352	6.3	12.4	15.5	125	56	25.2	43234	341	138	2	
FRI	12-22-78	2.7	14.2	1.35	0.13	1.03	2.51	9.6	4.86	1943	350	5.8	12.0	14.8	101	68	27.6	46130	400	124	1	
SAT	12-23-78	2.2	13.7	1.42	0.13	0.81	2.36	10.2	4.54	1648	345	6.1	12.1	14.5	106	56	23.8	28122	296	124	2	
SUN	12-24-78	3.4	20.8	1.32	0.12	0.53	1.97	12.2	4.22	1771	343	5.5	12.2	14.4	122	40	24.7	20819	332	120	1	
MON	12-25-78	2.6	10.5	1.59	0.14	0.87	2.60	9.2	5.57	1474	308	5.2	11.3	14.0	13	81	21.8	38804	408	148		
TUES	12-26-78	2.8	14.6	1.40	0.13	0.76	2.29	10.5	4.48	1930	350	4.2	12.0	14.8	147	64	22.9	27250	264	128	2	
WED	12-27-78	3.6	15.2	1.45	0.13	0.73	2.31	10.4	5.37	1868	356	5.0	10.8	13.6	148	47	25.2	20571	352	128	2	
THUR	12-28-78	2.8	20.2	1.29	0.12	0.55	1.96	12.2	4.77	2098	370	6.6	10.4	13.0	147	46	21.4	19388	320	128	1	
WEEKLY	AVG	2.9	15.6	1.40	0.13	0.75	2.29	10.6	4.83	1819	346	5.2	12.1	14.2	129	56	23.9	28726	336	128	2	
4-WEEK	AVG	3.2	17.5	1.38	0.13	0.86	2.33	10.5	5.18	2015	350	5.5	11.3	14.3	138	53	23.3	38553	348	132	4.8	

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APPENDIX B

WEEKLY AVERAGE VALUES OF DATA COLLECTED DURING PERIODS A, B, C, D, AND B'

TABLE B-1. SUMMARY OF DATA FOR PERIOD A

	Flow			BOD_5			TSS		
Week No.	Waste-water (mgd)	Return Sludge (mgd)	Bio-Cell Recircu-lation (mgd)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
1	3.12	1.53	3.46	183	126	15	151	78	9
2	3.09	1.58	3.41	180	102	9	142	73	8
3	3.11	1.65	3.34	143	122	11	137	80	10
4	3.08	1.54	3.15	198	142	13	151	69	7
5	3.18	1.52	3.08	185	150	14	139	78	10
6	3.35	1.49	3.30	225	168	14	139	88	10
7	3.46	1.57	3.27	186	129	18	121	70	11
8	3.52	1.75	3.60	186	127	16	119	74	11
9	3.71	1.93	3.84	178	140	16	134	74	11
10	4.21	1.88	4.02	168	125	15	124	58	11
11	5.44	2.24	3.48	144	110	14	116	60	9
12	4.75	2.54	2.73	120	115	17	90	74	13
AVG.	3.67	1.77	3.39	175	130	14	130	73	10

mgd x 3,785 = m^3/day

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TABLE B-1. (continued)

Week No.	COD Raw Waste-water (mg/1)	COD Primary Effluent (mg/1)	COD Secondary Effluent (mg/1)	TKN Raw Waste-water (mg/1)	TKN Primary Effluent (mg/1)	TKN Secondary Effluent (mg/1)	NH_4^+-N Raw Waste-water (mg/1)	NH_4^+-N Primary Effluent (mg/1)	NH_4^+-N Secondary Effluent (mg/1)
1	397	274	71	22.1	24.1	19.5	12.4	18.0	17.3
2	543	286	67	26.9	30.9	20.1	15.9	20.8	19.2
3	416	286	64	34.8	31.7	22.6	18.7	20.1	17.8
4	430	252	60	-	-	-	-	-	-
5	332	261	61	30.0	39.8	19.3	19.2	17.1	17.3
6	399	284	71	30.1	28.0	21.7	18.7	19.9	17.6
7	358	251	60	24.4	26.4	18.8	15.6	19.8	17.1
8	372	251	80	37.1	26.9	19.5	16.2	18.3	16.8
9	385	233	67	36.1	28.0	19.7	20.4	20.2	17.9
10	321	214	70	23.5	24.5	16.6	13.0	14.8	13.8
11	292	187	49	-	-	-	-	-	-
12	318	214	77	19.0	19.4	14.9	8.3	11.2	12.0
AVG.	380	249	66	28.4	28.0	19.3	15.8	18.0	16.7

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TABLE B-1. (continued)

Week No.	$NO_2^- + NO_3^-$-N Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Total P Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Alkalinity Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
1	0.1	0.1	0.0	5.2	5.4	5.1	-	-	-
2	0.3	0.1	0.1	7.2	8.3	7.4	170	183	174
3	0.0	0.0	0.1	6.3	6.4	5.7	166	172	170
4	-	-	-	-	-	-	-	-	-
5	0.0	0.0	0.1	7.9	9.1	6.3	172	170	164
6	0.4	0.0	0.1	8.5	7.7	6.1	186	182	178
7	0.4	0.1	0.2	8.0	8.6	6.7	166	178	162
8	0.5	0.2	0.1	9.1	8.4	6.1	162	170	170
9	0.3	0.1	0.1	10.8	7.9	6.4	174	168	160
10	0.1	0.2	0.6	8.7	7.6	5.9	154	152	150
11	-	-	-	-	-	-	-	-	-
12	-	-	-	4.8	5.4	4.1	99	126	125
AVG.	0.2	0.1	0.2	7.6	7.5	6.0	161	167	161

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TABLE B-1. (continued)

Week No.	Total BOD_5* Primary Effluent (mg/1)	Total BOD_5* Secondary Effluent (mg/1)	Soluble BOD_5 Primary Effluent (mg/1)	Soluble BOD_5 Secondary Effluent (mg/1)	Soluble BOD_5 Bio-Cell Effluent (mg/1)	Total COD† Primary Effluent (mg/1)	Total COD† Secondary Effluent (mg/1)	Bio-Cell Oxygen Uptake Rate (mg/1/hr)
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	37.8
4	142	15	75	10	13	-	-	37.8
5	158	16	79	6.8	14	276	52	34.6
6	166	14	72	17	8.9	275	67	33.2
7	-	-	-	-	-	-	-	35.2
8	144	15	75	15	6.2	277	83	43.5
9	183	20	61	8.4	6.1	264	64	31.4
10	163	21	73	8.4	6.2	229	89	39.0
11	112	15	50	4.9	9.2	207	66	42.3
12	133	20	57	8.1	7.4	207	75	52.3
AVG.	150	17	68	9.8	8.9	248	71	38.7

*Total BOD_5 values are average values for the same days in which soluble BOD_5 analyses were conducted.

†Total COD values are average values for the same days in which soluble COD analyses were conducted.

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

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TABLE B-1. (continued)

	Soluble COD			Mixed Liquor				Return Sludge	Waste Sludge		
Wk. No.	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Bio-Cell Effluent (mg/1)	TSS (mg/1)	VSS (mg/1)	Sludge Volume Index (ml/gm)	Aeration OUR (mg/1/hr)	TSS (mg/1)	Volume (gpd)	TSS (mg/1)	VSS (mg/1)
1	-	-	-	2,787	2,367	145	24.4	7,617	27,953	10,680	9,263
2	-	-	-	2,735	2,381	152	26.4	7,128	54,300	10,048	8,593
3	-	-	-	2,477	2,064	125	25.2	6,846	43,234	9,784	8,219
4	-	-	-	2,337	2,046	129	23.9	5,770	28,726	10,313	8,393
5	139	43	55	2,444	2,030	141	19.0	7,126	25,432	12,060	10,400
6	145	48	48	2,417	2,093	151	24.2	8,567	28,994	10,457	8,843
7	-	-	-	2,808	2,323	157	28.7	8,410	30,444	10,539	8,065
8	152	63	89	3,061	2,671	140	30.9	8,553	45,400	9,929	8,394
9	144	54	44	2,548	2,200	113	22.6	7,042	55,943	9,179	7,834
10	142	56	68	2,418	2,102	124	26.9	8,038	36,257	12,004	10,147
11	129	59	51	2,945	2,273	76	27.2	9,589	37,686	13,363	10,455
12	103	47	60	2,269	1,787	75	26.1	6,609	39,529	10,343	7,902
AVG.	136	53	59	2,604	2,195	127	25.5	7,608	37,825	10,725	8,876

gpd x 0.003785 = m^3/day

(continued)

TABLE B-1. (continued)

Week No.	Solids Residence Time (days)	Primary Effluent VSS (mg/1)	Temperature				Median pH		D.O.	
			Raw Waste-water (°C)	Primary Effluent (°C)	Secondary Effluent (°C)	Ambi-ent (°C)	Primary Effluent (units)	Secondary Effluent (units)	Bio-Cell Effluent (mg/1)	Aeration Basin (mg/1)
1	4.4	-	13	12	11	-10	7.3	7.1	7.2	3.5
2	2.7	-	14	13	11	-5	7.5	7.1	2.6	3.0
3	2.6	-	14	12	10	-4	7.5	7.2	7.6	4.1
4	2.9	-	13	13	10	-6	7.5	7.3	7.6	5.5
5	3.4	-	12	11	8	-23	7.3	7.2	8.4	5.2
6	2.9	-	12	10	9	-22	7.5	7.1	7.2	4.6
7	3.5	-	12	11	9	-16	7.5	7.0	7.8	3.4
8	2.8	-	12	11	9	-11	7.3	7.0	8.2	3.1
9	1.9	-	10	9	8	-21	7.5	7.4	7.9	2.6
10	2.3	-	10	9	8	-5	7.3	7.2	8.1	1.8
11	2.6	-	10	11	9	-4	7.4	7.0	8.0	1.8
12	2.2	-	10	10	8	-8	7.5	7.2	8.1	2.7
AVG.	2.9	-	11.8	11.0	9.2	-11.3	7.4	7.1	7.4	3.4

(continued)

TABLE B-1. (continued)

Week No.	Power Consumption		Weight Concentration to Spin Volume Ratio					
	Bio-Cell Pumping (kWh/day)	Aeration Blowers (kWh/day)	Mixed Liquor		Return Sludge		Waste Sludge	
			TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)
1	-	-	717	609	651	551	619	540
2	-	-	626	544	594	530	644	550
3	-	-	632	524	652	562	564	476
4	-	-	637	474	577	520	639	524
5	-	-	610	504	642	562	545	475
6	-	-	577	499	659	563	569	481
7	-	-	637	528	580	493	588	441
8	-	-	652	569	574	499	613	518
9	-	-	652	560	582	504	565	486
10	-	-	632	550	591	493	587	496
11	-	-	838	647	732	557	687	526
12	1479	-	846	668	806	797	735	563
AVG.	1479	-	671	556	637	553	613	465

TABLE B-2. SUMMARY OF DATA FOR PERIOD B

	Flow			BOD_5			TSS		
Week No.	Waste-water (mgd)	Return Sludge (mgd)	Bio-Cell Recirculation (mgd)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
13	4.68	2.54	0	125	129	17	136	79	15
14	4.92	1.78	0	116	104	19	124	85	25
15	4.29	1.94	0	128	120	20	140	91	28
16	3.70	2.10	0	137	129	18	215	116	28
17	3.86	1.78	0	130	115	17	218	90	23
18	3.75	1.81	0	130	117	27	146	112	33
19	3.77	2.06	0	148	114	33	176	92	32
20	3.69	1.93	0	124	118	30	181	97	43
21	3.84	1.90	0	123	111	28	146	107	48
22	3.67	1.94	0	145	112	21	173	94	28
23	3.58	2.00	0	181	156	24	159	140	39
24	3.47	1.96	0	134	155	21	152	129	31
25	3.48	1.96	0	232	158	24	299	100	17
26	3.35	1.90	0	163	141	15	151	96	20
27	3.39	1.95	0	188	153	21	289	102	24
28	3.42	2.01	0	160	148	30	387	174	38
29	3.75	1.91	0	138	123	16	333	137	17
30	3.57	1.90	0	163	129	18	153	195	18
31	3.35	2.04	0	119	108	11	127	80	13
32	3.43	2.00	0	165	113	11	171	109	14
AVG.	3.75	1.97	0	148	128	21	194	111	27

mgd x 3,785 = m^3/day

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TABLE B-2. (continued)

Week No.	COD Raw Waste-water (mg/1)	COD Primary Effluent (mg/1)	COD Secondary Effluent (mg/1)	TKN Raw Waste-water (mg/1)	TKN Primary Effluent (mg/1)	TKN Secondary Effluent (mg/1)	NH_4^+-N Raw Waste-water (mg/1)	NH_4^+-N Primary Effluent (mg/1)	NH_4^+-N Secondary Effluent (mg/1)
13	279	206	79	20.3	20.1	16.0	10.8	9.6	12.0
14	280	228	60	-	-	-	-	-	-
15	355	253	96	22.1	22.2	15.4	12.8	12.9	11.1
16	368	294	88	23.6	25.9	17.6	13.2	16.0	13.8
17	403	306	94	27.2	26.9	17.9	14.3	16.4	14.4
18	346	266	95	23.8	26.8	19.7	14.6	15.8	15.9
19	422	277	133	23.2	27.1	21.4	12.9	16.7	15.2
20	337	268	108	24.8	27.1	20.9	14.7	16.5	14.7
21	295	263	94	21.8	23.8	17.6	12.2	14.1	12.3
22	366	274	115	-	-	-	-	-	-
23	375	293	97	-	-	-	-	-	-
24	460	307	82	-	-	-	-	-	-
25	591	311	107	30.6	29.7	21.0	17.4	17.8	15.3
26	296	299	84	-	-	-	-	-	-
27	515	326	99	-	-	-	-	-	-
28	538	428	126	-	-	-	-	-	-
29	400	258	87	-	-	-	-	-	-
30	310	244	77	22.9	21.5	14.0	15.7	15.2	12.4
31	304	218	72	-	-	-	-	-	-
32	474	265	61	-	-	-	-	-	-
AVG.	386	279	93	24.0	25.1	18.2	13.9	15.1	13.7

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TABLE B-2. (continued)

Week No.	$NO_2^- + NO_3^-$-N Raw Waste-water (mg/1)	$NO_2^- + NO_3^-$-N Primary Effluent (mg/1)	$NO_2^- + NO_3^-$-N Secondary Effluent (mg/1)	Total P Raw Waste-water (mg/1)	Total P Primary Effluent (mg/1)	Total P Secondary Effluent (mg/1)	Alkalinity Raw Waste-water (mg/1)	Alkalinity Primary Effluent (mg/1)	Alkalinity Secondary Effluent (mg/1)
13	0.2	0.6	0.1	7.1	5.7	7.4	-	-	-
14	-	-	-	-	-	-	118	123	125
15	0.5	0.8	0.1	-	-	-	143	141	145
16	0.7	0.5	0.1	-	-	-	142	161	151
17	1.2	0.2	0.1	6.4	6.8	5.5	142	152	140
18	0.8	0.2	0.1	8.1	6.0	8.1	136	152	157
19	0.6	0.1	0.1	5.9	7.9	2.0	130	147	148
20	0.8	0.5	0.1	4.7	4.5	3.8	144	155	154
21	0.5	0.7	0.1	-	-	-	153	159	154
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-
25	0.2	0.0	0.2	9.9	9.3	6.2	173	180	173
26	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	154	174	173
31	0.0	0.1	0.3	7.7	9.1	6.5	-	-	-
32	-	-	-	-	-	-	-	-	-
AVG.	0.6	0.4	0.1	7.1	7.0	5.7	144	154	152

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TABLE B-2. (continued)

Week No.	Total BOD$_5$* Primary Effluent (mg/1)	Total BOD$_5$* Secondary Effluent (mg/1)	Soluble BOD$_5$ Primary Effluent (mg/1)	Soluble BOD$_5$ Secondary Effluent (mg/1)	Soluble BOD$_5$ Bio-Cell Effluent (mg/1)	Total COD† Primary Effluent (mg/1)	Total COD† Secondary Effluent (mg/1)	Bio-Cell Oxygen Uptake Rate (mg/1/hr)
13	158	18	56	10	8.1	225	65	42.6
14	96	12	46	8.1	7.9	208	88	42.2
15	135	19	72	8.4	8.4	266	87	54.0
16	136	18	68	10	10.5	296	87	65.4
17	116	16	57	5.5	6.7	264	102	56.6
18	125	22	46	6.3	10.2	277	94	52.0
19	129	31	64	8.0	9.7	282	133	46.3
20	122	31	74	9.0	13	283	101	58.3
21	123	24	58	9.3	11	270	133	57.6
22	161	27	57	10	10	283	85	70.2
23	127	21	47	5.1	5.8	-	-	83.3
24	175	22	61	7.2	12	297	88	81.4
25	157	22	36	8.9	8.2	343	95	74.9
26	158	15	64	5.2	6.2	307	93	61.0
27	150	21	64	9.4	12	311	97	79.7
28	145	22	44	8.6	8.2	285	100	89.0
29	113	19	43	8.3	8.1	266	131	66.2
30	143	20	48	6.9	8.3	235	88	81.0
31	167	12	66	8.5	9.7	323	63	56.0
32	106	8.0	54	3.1	4.7	262	74	66.3
AVG.	137	20	56	7.8	8.9	278	95	64.2

*Total BOD$_5$ values are average values for the same days in which soluble BOD$_5$ analyses were conducted.

†Total COD values are average values for the same days in which soluble COD analyses were conducted.

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TABLE B-2. (continued)

	Soluble COD			Mixed Liquor				Return Sludge	Waste Sludge		
Wk. No.	Primary Effluent (mg/l)	Secondary Effluent (mg/l)	Bio-Cell Effluent (mg/l)	TSS (mg/l)	VSS (mg/l)	Sludge Volume Index (ml/gm)	Aeration OUR (mg/l/hr)	TSS (mg/l)	Volume (gpd)	TSS (mg/l)	VSS (mg/l)
13	115	57	43	2,866	1,869	78	34.6	8,343	39,414	9,886	7,633
14	106	36	61	2,693	2,023	68	33.3	9,784	19,957	18,267	14,173
15	150	59	53	3,516	2,538	63	39.6	9,755	18,951	17,367	11,404
16	159	57	66	4,614	3,528	69	44.4	11,782	25,143	19,109	14,583
17	128	50	46	3,729	2,754	90	36.8	11,357	28,043	19,140	13,105
18	138	64	62	3,201	2,395	84	32.6	8,978	32,129	18,344	14,242
19	149	56	74	2,558	2,003	81	34.9	6,922	25,200	21,642	16,097
20	146	59	72	2,691	2,175	84	35.8	9,342	26,929	17,214	13,561
21	147	63	74	2,899	2,351	85	41.3	10,697	26,185	18,400	15,174
22	163	72	64	3,469	2,587	80	43.5	8,617	22,732	19,440	15,120
23	-	-	-	4,024	3,182	100	41.2	10,025	18,295	20,679	15,271
24	141	62	79	4,227	3,369	136	53.0	10,692	32,363	18,830	15,072
25	99	70	72	3,734	2,877	160	49.6	11,361	39,758	16,505	12,838
26	150	86	84	3,906	3,093	90	39.4	9,378	27,729	17,400	14,451
27	149	77	70	3,960	2,740	105	55.9	9,052	30,227	17,368	14,914
28	141	71	64	4,787	3,947	116	60.4	10,390	35,350	17,269	13,949
29	105	56	44	5,210	2,884	94	38.2	13,553	38,292	17,605	11,179
30	156	69	71	5,003	3,350	71	48.1	12,558	34,811	20,620	14,056
31	144	43	39	3,547	2,624	80	25.9	9,325	28,764	18,556	13,659
32	139	55	59	3,376	2,409	76	34.5	8,299	31,183	16,203	11,774
AVG.	138	61	63	3,701	2,735	91	41.2	10,011	29,073	17,992	13,613

gpd x 0.003785 = m^3/day

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TABLE B-2. (continued)

			Temperature				Median pH			
							Median pH		D.O.	
Week No.	Solids Residence Time (days)	Primary Effluent VSS (mg/1)	Raw Waste-water (°C)	Primary Effluent (°C)	Secondary Effluent (°C)	Ambi-ent (°C)	Primary Effluent (units)	Secondary Effluent (units)	Bio-Cell Effluent (mg/1)	Aeration Basin (mg/1)
13	2.9	-	10	10	9	-4	7.4	7.1	8.1	2.2
14	2.8	-	10	10	9	-1	7.3	7.0	7.6	1.0
15	5.3	-	10	10	10	4	7.3	7.0	7.2	2.5
16	3.6	-	11	11	10	4	7.3	7.1	6.7	1.3
17	3.0	-	10	10	10	-1	7.3	7.0	7.0	1.6
18	2.0	-	11	11	9	1	7.3	7.1	6.9	3.3
19	1.8	-	11	11	10	6	7.3	7.1	7.0	1.4
20	1.8	-	12	12	10	7	7.4	7.0	8.8	2.0
21	1.6	-	13	12	11	6	7.4	7.1	5.9	2.7
22	2.4	66	11	11	12	10	7.6	7.1	6.7	2.7
23	2.7	116	13	13	13	9	7.4	7.0	6.5	3.1
24	2.6	101	12	12	13	15	7.6	7.0	6.5	2.2
25	2.4	78	12	12	16	16	7.4	7.0	5.6	1.1
26	2.6	64	14	14	14	15	7.4	6.9	6.4	2.5
27	3.0	82	13	14	15	18	7.4	7.1	5.3	2.2
28	3.0	164	15	15	15	20	7.6	7.0	5.9	1.4
29	2.5	96	16	16	16	17	7.4	7.0	5.3	2.8
30	2.5	220	16	16	17	22	7.8	7.0	5.9	2.1
31	2.4	71	16	16	17	20	7.8	7.2	6.2	4.3
32	2.4	66	17	17	17	23	7.8	7.1	5.8	3.3
AVG.	2.7	102	12.7	12.7	13.2	10.4	7.4	7.0	6.6	2.3

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TABLE B-2. (continued)

Week No.	Power Consumption		Weight Concentration to Volume Spin Ratio					
	Bio-Cell	Aeration	Mixed Liquor		Return Sludge		Waste Sludge	
	Pumping (kWh/day)	Blowers (kWh/day)	TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)
13	1,085	-	784	600	810	633	787	608
14	1,011	-	839	636	789	581	768	595
15	915	-	818	590	739	510	721	473
16	866	759	834	641	741	455	722	543
17	837	801	634	468	624	484	629	499
18	924	785	549	486	583	428	605	469
19	845	646	671	527	721	596	669	543
20	809	670	602	490	-	-	510	404
21	833	633	633	513	849	691	581	481
22	809	821	736	550	668	419	686	533
23	802	818	680	541	651	525	622	471
24	778	824	649	517	661	509	653	525
25	775	929	596	458	697	526	601	466
26	759	924	754	595	727	594	628	521
27	770	1049	803	559	691	481	785	657
28	786	1051	819	673	702	559	708	573
29	857	1006	883	482	922	649	765	613
30	783	973	970	652	897	623	895	613
31	781	1078	842	627	818	605	807	579
32	989	1082	804	577	741	555	691	499
AVG.	846	873	745	559	738	554	692	533

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TABLE B-3. SUMMARY OF DATA FOR PERIOD C

Week No.	Flow			BOD$_5$			TSS		
	Waste-water (mgd)	Return Sludge (mgd)	Bio-Cell Recirculation (mgd)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
36	3.49	1.97	0	161	132	27	140	101	28
37	3.75	2.14	0	152	134	33	179	93	24
38	3.58	2.02	0	155	116	32	148	89	25
39	3.45	2.02	0	168	132	21	150	101	21
40	3.20	1.99	0	168	135	19	163	103	26
41	3.40	2.01	0	158	137	23	182	93	18
42	3.29	2.01	0	180	120	27	142	86	21
43	3.35	1.99	0	150	126	24	141	99	19
44	3.36	2.16	0	138	127	25	160	94	19
45	3.40	2.11	0	161	147	30	211	119	20
46	3.17	1.97	0	150	119	25	159	102	22
47	3.18	2.04	0	181	128	22	193	101	20
48	3.21	1.77	0	147	124	25	210	151	34
49	3.19	1.88	0	133	137	24	193	133	22
50	3.12	1.82	0	131	124	23	253	138	24
51	3.10	2.01	0	123	98	20	226	83	20
52	3.07	1.87	0	142	111	23	392	121	19
53	3.22	1.91	0	118	103	17	497	141	20
54	3.21	1.93	0	142	104	19	336	125	16
55	3.17	1.87	0	136	117	19	206	98	21
56	3.03	1.93		185	140	23	181	98	23
57	3.17	1.92		165	119	23	206	106	22
58	3.00	1.96		-	-	-	247	125	22
AVG.	3.27	1.97	0	152	124	24	214	109	22

mgd x 3,785 = m^3/day

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TABLE B-3. (continued)

Week No.	COD Raw Waste-water (mg/1)	COD Primary Effluent (mg/1)	COD Secondary Effluent (mg/1)	TKN Raw Waste-water (mg/1)	TKN Primary Effluent (mg/1)	TKN Secondary Effluent (mg/1)	NH_4^+-N Raw Waste-water (mg/1)	NH_4^+-N Primary Effluent (mg/1)	NH_4^+-N Secondary Effluent (mg/1)
36	321	269	106	-	-	-	-	-	-
37	563	312	109	-	-	-	-	-	-
38	358	259	99	-	-	-	-	-	-
39	467	278	88	-	-	-	-	-	-
40	513	275	87	24.2	25.9	17.4	14.2	17.1	13.6
41	539	257	78	-	-	-	-	-	-
42	539	285	103	-	-	-	-	-	-
43	363	261	75	-	-	-	-	-	-
44	380	311	86	21.6	24.2	17.4	15.4	16.5	12.5
45	420	282	89	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-
47	437	285	92	26.1	27.3	19.1	16.5	18.4	16.5
48	403	289	97	-	-	-	-	-	-
49	415	278	96	-	-	-	-	-	-
50	438	248	80	-	-	-	-	-	-
51	432	323	91	26.9	26.3	18.9	17.9	19.7	16.1
52	415	268	82	-	-	-	-	-	-
53	407	256	85	-	-	-	-	-	-
54	500	261	88	-	-	-	-	-	-
55	394	288	85	-	-	-	-	-	-
56	-	-	-	-	-	-	-	-	-
57	383	252	71	-	-	-	-	-	-
58	499	254	81	28.9	26.6	18.7	16.7	13.1	20.5
AVG.	437	276	89	25.5	26.1	18.3	16.1	16.9	15.8

(continued)

TYPING GUIDE SHEET
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(4-76)

TABLE B-3. (continued)

Week No.	$NO_2^- + NO_3^-$-N Raw Waste-water (mg/1)	$NO_2^- + NO_3^-$-N Primary Effluent (mg/1)	$NO_2^- + NO_3^-$-N Secondary Effluent (mg/1)	Total P Raw Waste-water (mg/1)	Total P Primary Effluent (mg/1)	Total P Secondary Effluent (mg/1)	Alkalinity Raw Waste-water (mg/1)	Alkalinity Primary Effluent (mg/1)	Alkalinity Secondary Effluent (mg/1)
36	-	-	-	-	-	-	-	-	-
37	0.1	0.1	0.7	-	-	-	149	160	175
38	-	-	-	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-
40	-	-	-	10.5	10.2	4.7	-	-	-
41	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-
44	0.1	0.4	0.3	7.5	9.3	5.6	-	-	-
45	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-
47	0.0	0.0	0.3	8.8	6.5	5.2	130	146	142
48	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-
51	0.3	0.5	0.9	8.6	11.5	6.5	167	166	153
52	-	-	-	-	-	-	-	-	-
53	-	-	-	-	-	-	-	-	-
54	-	-	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-	-	-
57	-	-	-	-	-	-	-	-	-
58	0.4	0.4	0.2	6.4	5.2	3.6	193	196	209
AVG.	0.2	0.3	0.5	8.4	8.5	5.1	160	167	170

(continued)

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TABLE B-3. (continued)

Week No.	Total BOD$_5$*		Soluble BOD$_5$			Total COD†		Bio-Cell Oxygen Uptake Rate (mg/1/hr)
	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Bio-Cell Effluent (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	
36	138	29	60	14	13	224	110	111.8
37	156	42	90	20	23	367	146	104.9
38	158	38	76	20	11	310	88	116.5
39	150	21	77	9.5	8.3	301	79	98.8
40	121	19	62	7.5	6.4	255	82	91.6
41	113	28	45	8.1	7.1	240	69	81.7
42	120	29	74	14	12	265	87	122.5
43	133	28	63	8.0	12	281	79	106.9
44	134	29	66	8.5	9.8	275	83	89.9
45	127	23	80	13	18	282	82	85.3
46	-	-	-	-	-	-	-	92.7
47	134	25	74	14	12	288	91	90.7
48	136	29	65	8	18	310	103	97.8
49	124	26	57	24	9.9	292	110	81.5
50	93	17	44	13	9.8	239	63	104.0
51	108	20	39	6.4	8.9	248	88	79.5
52	122	22	54	7.2	8.2	304	88	79.8
53	108	18	52	8	11	273	79	76.6
54	129	23	55	17	7.9	281	86	77.3
55	101	18	64	11	10	290	76	71.1
56	-	-	-	-	-	-	-	84.3
57	-	-	-	-	-	-	-	72.1
58	-	-	-	-	-	-	-	54.5
AVG.	127	25	63	12	11	280	89	90.1

*Total BOD$_5$ values are average values for the same days in which soluble BOD$_5$ analyses were conducted.

†Total COD values are average values for the same days in which soluble COD analyses were conducted.

(continued)

TABLE B-3. (continued)

	Soluble COD			Mixed Liquor				Return Sludge	Waste Sludge		
Wk. No.	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Bio-Cell Effluent (mg/1)	TSS (mg/1)	VSS (mg/1)	Sludge Volume Index (ml/gm)	Aeration OUR (mg/1/hr)	TSS (mg/1)	Volume (gpd)	TSS (mg/1)	VSS (mg/1)
36	151	82	81	3,647	2,896	63	58.7	10,110	17 821	16,338	11,905
37	200	100	111	2,485	2,130	65	58.5	6,803	14,884	19,354	15,727
38	161	81	55	4,349	3,229	61	62.9	10,960	19,065	20,323	15,590
39	171	75	72	3,053	2,254	54	58.7	8,035	16,804	18,037	13,640
40	148	54	63	3,885	2,961	77	57.2	10,100	18,302	18,354	13,793
41	126	57	57	4,184	3,105	97	56.1	11,125	28,473	17,707	11,707
42	158	95	69	4,094	3,344	104	67.7	10,135	24,145	17,209	13,894
43	149	66	59	3,555	2,820	131	61.8	9,980	29,391	15,799	12,361
44	167	68	86	3,351	2,599	126	59.1	8,095	18,941	16,631	12,643
45	133	56	53	3,499	2,740	113	65.1	7,360	22,906	17,453	14,207
46	-	-	-	2,937	2,363	108	52.7	6,985	18,876	15,590	12,564
47	179	74	76	3,427	2,688	105	65.3	8,500	13,347	18,423	15,089
48	143	76	76	4,589	3,385	111	51.9	11,920	17,835	22,017	17,407
49	166	70	62	4,108	3,306	115	58.0	10,060	20,400	19,533	16,047
50	152	73	73	3,690	2,835	112	52.7	9,430	18,462	18,387	14,361
51	130	36	54	3,465	2,561	102	49.0	8,005	14,289	16,914	14,050
52	144	81	57	3,020	2,434	118	46.0	8,025	17,384	18,329	12,054
53	129	61	54	3,570	2,943	94	52.5	8,985	18,858	19,393	13,571
54	133	63	61	3,616	2,881	121	52.3	9,110	19,411	17,543	15,054
55	149	55	63	3,486	2,834	110	44.7	8,880	22,571	17,752	14,241
56	-	-	-	3,326	2,782	96	52.2	8,140	18,331	18,841	13,998
57	-	-	-	3,733	2,921	107	51.0	8,615	18,605	18,372	13,641
58	-	-	-	3,600	2,851	106	40.0	8,430	19,453	20,200	15,204
AVG.	152	70	67	3,594	2,820	100	55.4	9,034	19,502	18,196	14,033

gpd x 0.003785 = m^3/day

(continued)

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TABLE B-3. (continued)

Week No.	Solids Residence Time (days)	Primary Effluent VSS (mg/l)	Temperature: Raw Waste-water (°C)	Temperature: Primary Effluent (°C)	Temperature: Secondary Effluent (°C)	Temperature: Ambi-ent (°C)	Median pH: Primary Effluent (units)	Median pH: Secondary Effluent (units)	D.O.: Bio-Cell Effluent (mg/l)	D.O.: Aeration Basin (mg/l)
36	2.8	81	19	19	20	23	7.3	7.0	3.0	2.5
37	2.2	69	19	19	19	20	7.2	6.9	4.7	2.1
38	2.4	61	19	19	20	21	7.0	6.9	5.2	3.0
39	2.3	84	18	18	19	18	7.6	7.0	6.1	4.5
40	2.6	80	18	18	19	17	7.2	7.0	5.2	3.6
41	1.9	69	18	18	19	16	7.4	7.0	6.0	3.0
42	2.0	67	18	18	19	16	7.6	6.9	4.1	2.2
43	2.0	78	17	18	18	16	7.5	6.9	4.2	2.7
44	2.0	76	17	17	18	13	7.4	7.0	5.0	2.1
45	1.9	82	17	17	18	14	7.8	7.0	5.0	1.9
46	1.9	80	16	16	17	9.5	7.4	7.0	4.7	2.1
47	2.2	-	-	-	16	6.3	-	6.9	4.6	2.5
48	2.0	120	16	16	16	2.2	7.4	7.0	4.3	3.2
49	2.1	104	15	15	15	0.4	7.4	6.9	5.6	2.6
50	2.2	122	12	12	13	1.1	7.2	7.0	5.9	3.1
51	2.2	62	13	13	14	-2.3	7.6	7.0	5.4	2.3
52	2.4	91	14	14	14	-8.1	7.4	7.0	5.6	2.4
53	2.5	116	14	14	13	2.3	7.3	7.0	6.0	2.3
54	2.4	102	13	13	12	-0.2	7.3	7.0	5.3	2.4
55	2.2	83	13	11	11	-8.4	7.2	7.0	6.7	2.9
56	2.1	77	13	13	11	-2.3	7.4	7.0	6.0	2.0
57	2.2	92	13	13	10	-	7.4	7.0	6.4	2.2
58	2.2	110	-	-	8.8	-	-	7.0	6.3	1.7
AVG.	2.2	87	15.8	15.8	15.6	8.3	7.4	7.0	5.3	2.6

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TABLE B-3. (continued)

Week No.	Power Consumption		Weight Concentration to Volume Spin Ratio					
	Bio-Cell Pumping (kWh/day)	Aeration Blowers (kWh/day)	Mixed Liquor		Return Sludge		Waste Sludge	
			TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)	TSS (mg/1/%)	VSS (mg/1/%)
36	823	991	869	691	890	684	753	555
37	1,138	998	741	636	802	666	726	580
38	1,140	1,298	782	581	645	515	714	548
39	1,111	1,198	875	640	804	590	687	522
40	1,071	1,277	747	578	798	635	724	545
41	1,027	1,101	725	538	709	521	689	511
42	833	994	733	600	681	481	616	498
43	972	1,480	641	508	616	606	596	467
44	1,994	832	689	534	648	412	638	486
45	969	799	733	575	676	611	650	529
46	977	823	693	543	681	545	631	506
47	1,923	874	628	560	691	594	566	532
48	934	1,256	688	521	598	489	558	442
49	726	873	660	530	585	465	614	509
50	722	665	690	530	679	478	596	472
51	737	763	656	485	572	387	678	562
52	703	728	587	473	643	544	651	434
53	720	720	705	579	646	532	708	500
54	737	790	643	530	599	502	554	475
55	734	735	715	578	716	544	586	471
56	715	593	749	619	708	603	638	475
57	708	633	750	587	703	576	643	477
58	720	578	766	608	736	479	680	510
AVG.	962	913	716	566	688	542	648	505

TABLE B-4. SUMMARY OF DATA FOR PERIOD D

	Flow			BOD_5			TSS		
Week No.	Wastewater (mgd)	Return Sludge (mgd)	Bio-Cell Recirculation (mgd)	Raw Wastewater (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Wastewater (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
59	3.02	1.81	0	161	146	21	184	129	25
60	2.97	1.65	0	158	(158)	25	140	(140)	33
61	3.03	1.69	0	116	(116)	28	154	(154)	34
62	2.97	1.56	0	175	148	26	160	102	19
63	2.91	1.77	0	155	128	27	152	94	20
64	2.95	1.87	0	162	133	42	172	106	37
65	3.17	1.67	0	181	148	48	191	174	38
AVG.	3.00	1.72	0	158	140	31	165	128	29

mgd x 3,785 = m^3/day

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TABLE B-4. (continued)

	COD			TKN			NH_4^+-N		
Week No.	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
59	374	296	84	-	-	-	-	-	-
60	336	(336)	113	-	-	-	-	-	-
61	347	(347)	108	-	-	-	-	-	-
62	381	282	75	19.5	27.1	21.2	18.1	18.3	16.9
63	427	288	76	-	-	-	-	-	-
64	450	319	102	-	-	-	-	-	-
65	382	272	103	-	-	-	-	-	-
AVG.	385	306	94	19.5	27.1	21.2	18.1	18.3	16.9

(continued

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TABLE B-4. (continued)

Week No.	$NO_2^- + NO_3^-$-N Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Total P Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Alkalinity Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
59	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
61	-	-	-	-	-	-	-	-	-
62	0.4	0.3	0.1	8.1	7.7	6.0	212	211	-
63	-	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-	-
AVG.	0.4	0.3	0.1	8.1	7.7	6.0	212	211	-

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TABLE B-4. (continued)

Week No.	Total BOD_5* Primary Effluent (mg/1)	Total BOD_5* Secondary Effluent (mg/1)	Soluble BOD_5 Primary Effluent (mg/1)	Soluble BOD_5 Secondary Effluent (mg/1)	Soluble BOD_5 Bio-Cell Effluent (mg/1)	Total COD† Primary Effluent (mg/1)	Total COD† Secondary Effluent (mg/1)	Bio-Cell Oxygen Uptake Rate (mg/1/hr)
59	-	-	-	-	-	-	-	62.5
60	165	32	83	21	23	-	-	65.8
61	127	31	72	17	13	392	115	74.2
62	142	28	67	13	16	207	76	72.5
63	147	39	64	13	20	321	115	69.7
64	161	48	74	16	31	381	120	72.8
65	183	75	55	25	25	309	130	64.1
AVG.	154	42	69	18	17	322	111	68.8

*Total BOD_5 values are average values for the same days in which soluble BOD_5 analyses were conducted.

†Total COD values are average values for the same days in which soluble COD analyses were conducted.

(continued)

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TABLE B-4. (continued)

Wk. No.	Soluble COD Primary Effluent (mg/1)	Soluble COD Secondary Effluent (mg/1)	Soluble COD Bio-Cell Effluent (mg/1)	Mixed Liquor TSS (mg/1)	Mixed Liquor VSS (mg/1)	Mixed Liquor Sludge Volume Index (ml/gm)	Mixed Liquor Aeration OUR (mg/1/hr)	Return Sludge TSS (mg/1)	Waste Sludge Volume (gpd)	Waste Sludge TSS (mg/1)	Waste Sludge VSS (mg/1)
59	-	-	-	3,956	3,333	86	53.0	8,965	17,710	21,203	17,366
60	-	-	-	4,069	2,878	60	53.7	12,312	22,761	23,057	18,593
61	154	71	71	4,590	3,774	60	47.7	16,403	17,482	24,097	21,057
62	135	53	60	3,731	3,014	61	47.1	11,226	14,863	26,745	21,474
63	159	72	80	3,295	2,659	63	52.4	8,763	16,785	22,804	18,282
64	154	76	91	3,036	2,474	61	56.0	8,281	11,803	27,242	22,908
65	120	76	68	3,480	2,845	61	48.6	8,447	8,670	29,928	23,579
AVG.	144	70	74	3,737	2,997	65	51.2	10,628	15,725	25,011	20,466

gpd x 0.003785 = m^3/day

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TABLE B-4. (continued)

Week No.	Solids Residence Time (days)	Primary Effluent VSS (mg/1)	Temperature				Median pH		D.O.	
			Raw Waste-water (°C)	Primary Effluent (°C)	Secondary Effluent (°C)	Ambi-ent (°C)	Primary Effluent (units)	Secondary Effluent (units)	Bio-Cell Effluent (mg/1)	Aeration Basin (mg/1)
59	2.4	-	11	11	10	-0.5	7.3	7.0	6.6	1.5
60	2.3	-	12	(12)	10	-7.1	(7.5)	6.9	6.3	3.3
61	2.4	-	-	-	10	-21	-	7.2	6.9	4.0
62	2.6	-	-	-	11	+0.4	-	7.1	5.7	2.1
63	2.4	-	10	10	10	-8.5	7.3	7.0	5.9	1.5
64	2.1	-	11	11	10	-7.9	7.4	7.1	6.7	1.5
65	2.3	-	-	11	10	-0.9	7.3	7.0	6.7	4.0
AVG.	2.4	-	11	11	10	-6.5	7.3	7.1	6.4	2.6

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TABLE B-4. (continued)

Week No.	Power Consumption: Bio-Cell Pumping (kWh/day)	Power Consumption: Aeration Blowers (kWh/day)	Weight Concentration to Spin Volume Ratio: Mixed Liquor TSS (mg/1/%)	Mixed Liquor VSS (mg/1/%)	Return Sludge TSS (mg/1/%)	Return Sludge VSS (mg/1/%)	Waste Sludge TSS (mg/1/%)	Waste Sludge VSS (mg/1/%)
59	759	583	815	688	724	653	735	601
60	710	819	1,043	740	1,080	878	980	758
61	708	840	1,034	835	1,402	912	858	741
62	681	754	929	751	877	743	886	688
63	691	754	805	648	749	526	789	630
64	703	741	797	646	746	567	752	631
65	710	730	924	758	761	614	756	595
AVG.	709	746	907	724	906	699	822	663

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TABLE B-5. SUMMARY OF DATA FOR PERIOD B'

	Flow			BOD$_5$			TSS		
Week No.	Waste-water (mgd)	Return Sludge (mgd)	Bio-Cell Recircu-lation (mgd)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)	Raw Waste-water (mg/1)	Primary Effluent (mg/1)	Secondary Effluent (mg/1)
1A	2.89	1.76	0	142	116	24	172	106	27
2A	2.86	1.83	0	152	117	23	167	89	17
3A	3.81	1.74	0	175	141	36	197	101	25
4A	2.84	1.65	0	210	139	35	223	142	23
5A	2.83	1.61	0	162	122	24	196	129	20
6A	2.93	1.56	0	162	122	18	214	124	19
7A	3.16	1.76	0	184	116	15	215	91	15
8A	3.56	1.87	0	180	108	22	259	100	15
9A	3.14	1.82	0	197	109	18	233	78	11
10A	3.76	1.94	0	146	102	16	147	97	16
11A	3.55	1.84	0	160	98	13	164	77	13
12A	3.67	1.89	0	161	88	13	191	86	12
13A	3.65	1.99	0	153	108	11	166	99	14
14A	3.68	2.13	0	153	101	15	201	101	13
15A	3.35	2.03	0	150	97	14	218	88	13
16A	3.50	1.98	0	140	101	13	174	129	12
AVG.	3.26	1.84	0	164	112	19	196	102	17

(continued)

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TABLE B-5. (continued)

	D.O.		Mixed Liquor					Waste Sludge		
Wk. No.	Bio-Cell Effluent (mg/1)	Aeration Basin (mg/1)	TSS (mg/1)	VSS (mg/1)	Sludge Volume Index (ml/gm)	Aeration OUR (mg/1/hr)	Return Sludge TSS (mg/1)	Volume (gpd)	TSS (mg/1)	VSS (mg/1)
1A	6.9	3.6	1,855	1,395	42	27.1	4,507	8,536	21,376	15,680
2A	6.4	2.3	1,827	1,386	46	22.8	4,920	5,712	29,029	22,313
3A	-	3.3	2,011	1,879	44	23.9	5,320	10,550	26,865	16,484
4A	-	3.4	4,057	2,938	44	35.3	11,529	29,823	22,862	16,105
5A	-	3.6	4,444	2,852	55	36.1	11,278	32,315	21,948	15,557
6A	-	3.1	3,766	2,525	57	37.1	7,570	30,091	18,917	13,662
7A	-	3.0	3,644	2,729	66	34.2	9,146	34,374	17,748	13,329
8A	-	1.8	3,559	2,413	61	31.8	8,606	29,609	18,980	15,187
9A	-	1.5	3,271	2,477	72	38.8	7,099	30,891	16,121	10,984
10A	-	1.4	3,711	2,564	64	36.8	9,675	19,992	25,398	19,197
11A	-	1.9	3,812	2,791	72	29.4	9,977	32,282	17,738	13,098
12A	-	1.9	3,954	2,954	77	32.8	9,731	36,210	21,941	16,114
13A	-	2.2	4,076	2,810	70	36.7	11,966	31,664	22,202	15,312
14A	-	2.2	3,879	2,894	86	42.2	9,936	37,521	17,702	12,746
15A	-	1.4	3,561	2,667	93	42.3	9,546	29,821	20,202	15,600
16A	-	3.0	3,727	2,623	85	36.6	9,903	31,088	17,176	12,048
AVG.	-	2.5	3,447	2,494	65	34.6	8,789	26,905	21,013	15,214

APPENDIX C

SCREENING FOR SELECTED PRIORITY POLLUTANTS

The presence of organic compounds and metals in water supplies and their fate during passage through wastewater treatment plants are receiving increasing attention in the environmental field. Some 129 of these compounds and metals with potential health-related impacts have been designated as priority or Consent Decree (1) pollutants by the U.S. Environmental Protection Agency (EPA).

During the Helena ABF project, a decision was made to conduct a 1-day priority pollutant sampling and screening program at the Helena site. The samples were collected over a 24-hr period from 8:00 A.M., February 19, 1980, to 8:00 A.M., February 20, 1980. The analytical results obtained provide perspective on the concentrations of priority pollutants in Helena's wastewater and the combined efficiency of primary clarification and the ABF process in removing same.

SAMPLING AND ANALYTICAL METHODS

Grab samples for subsequent compositing were selected at well-mixed points for four Helena plant streams: raw wastewater influent, primary effluent, secondary effluent before chlorination, and chlorinated secondary effluent. The samples were taken at time 0 and after each successive one-twelfth fraction of expected daily plant flow. Two aliquots of sample were selected at each sampling interval: one sample in a 700-ml glass bottle with a teflon-lined cap and a second sample in a 30-ml vial with a sealed teflon-faced septum and a screw cap.

Samples of primary and secondary effluents were obtained by manually submerging a sample container to an appropriate point, removing the cap on the container, and filling the sample container held in the vertical position. The container was then tightly capped while still submerged.

Samples of raw wastewater and chlorinated secondary effluent were obtained by locking two uncapped containers (one 100-ml bottle and one 30-ml vial) vertically in a bucket and lowering the bucket into the appropriate sample stream. After filling the bucket, the bucket was quickly withdrawn and the submerged containers capped in the full bucket.

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(1) Natural Resources Defense Council (NRDC) et al. vs. Train 8 ERC 2120 (DDC 1976).

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Sodium thiosulfate crystals for dechlorination were placed in the containers designated for collection of chlorinated secondary effluent samples before filling the containers. Air bubbles were carefully excluded from the 30-ml samples to prevent loss of volatile (purgeable) organics. All samples were stored at 2-5°C until completion of the 24-hr compositing period.

Samples were then iced, sealed in insulated containers, and shipped by air freight to laboratories of the Waste Identification and Analysis Section of EPA's Municipal Environmental Research Laboratory in Cincinnati, Ohio. All samples were delivered to analytical laboratory within 24 hr after selection of the final grab samples. The individual samples were then composited by the laboratory before analysis for priority organics and selected metals.

The samples for volatile (purgeable) organics were composited by a special technique to minimize losses of volatiles. The 12 iced 30-ml samples were simultaneously added to a compositing container, all at 3°C in a cold room. Three replicated 30-ml composite samples were then quickly selected for the volatile organics analyses.

The composited samples were analyzed for priority organic pollutants by standard test procedures for analysis of priority pollutants (2). The four most volatile priority organics, chloromethane, chloroethane, bromomethane, and vinyl chloride, were not included in the analyses. The semivolatile priority organic, 2,3,7,8 - tetrachlorodibenzopara - dioxin (TCDD), also was excluded from the analytical program due to the extreme toxicity of the related laboratory standards and special laboratory requirements for the procedure. Metals concentrations were determined by EPA's standard atomic adsorption procedures (3).

ANALYTICAL RESULTS

The results of this 1-day priority pollutant screening effort are summarized in Table C-1. . Semivolatile (extractable) priority organics data are given in Table C-2. The analytical resuts for metals are shown in Table C-3.

The concentrations of the three classes of priority materials measured at Helena are well within the ranges found at other cities. The numbers of compounds detected are also typical of other sites. Observed percentage removals are representative of what would normally be expected for these types of pollutants in a municipal wastewater treatment plant, i.e., low if any removal across the primary clarifier and substantial removal (in most cases) across the biological system. Chlorination of secondary effluent produced an increase in the concentrations of most of the volatiles and some of the semivolatiles, although caution is recommended in attempting to interpret the significance of these results on the basis of one 24-hr composite sample.

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(2) Federal Register, 44 (233), December 3, 1979, "Guidelines Establishing Test Procedures for Analysis of Pollutants, Proposed Regulations," pp. 69526-69558.

(3) "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio (March 1979).

TABLE C-1. VOLATILE (PURGEABLE) PRIORITY ORGANICS DATA*

Compound	Concentration (μg/l) Raw Waste-water	Primary Effluent	Unchlorinated Secondary Effluent	Chlorinated Secondary Effluent
Methyl chloride	1.5	2.7	2.5	6.7
Trichlorofluoromethane	0.7	0.2	---	---
1,1-Dichloroethene	0.5	1.2	---	---
Bromochloromethane	19.2	19.4	5.8	17.0
1,1-Dichloroethane	0.1	---	---	---
Trans-1,2-Dichloroethane	1.0	1.0	---	0.3
Chloroform	4.8	4.7	0.7	2.3
1,2-Dichloroethane	0.6	1.3	---	---
1,1,1-Trichloroethane	4.5	6.2	0.8	1.1
Carbon tetrachloride	1.4	1.9	---	---
Bromodichloromethane	0.6	0.3	---	---
Trichloroethene	0.4	3.4	0.4	0.9
Dibromochloromethane	0.4	0.5	---	---
Benzene	2.4	2.9	1.7	3.5
2-Bromochloroethane (SS)	18.7	19.1	17.2	17.6
Bromoform	---	1.8	---	---
1,1,2,2-Tetrachloroethane	16.1	14.5	---	---
Tetrachloroethene	16.8	14.8	2.5	1.0
Dichlorobutane (SS)	19.1	19.8	17.8	20.3
Toluene	3.0	4.0	1.1	1.9
Chlorobenzene	0.4	0.5	---	---
Ethylbenzene	1.5	1.4	0.4	0.6

*Screened for all purgeable (volatile) priority organics except the four most volatile compounds: chloromethane, chloroethane, bromomethane, and vinyl chloride. Compounds that were not detected in any of the samples from the four sample points are not included in the above lists.

--- Means not detected.

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TABLE C-2. SEMIVOLATILE (EXTRACTABLE) PRIORITY ORGANICS DATA*

Compound	Concentration (μg/1) Raw Wastewater	Primary Effluent	Unchlorinated Secondary Effluent	Chlorinated Secondary Effluent
2-Nitrophenol	---	---	6.7	---
Phenol	21	20	3	---
2,4-Dimethylphenol	---	---	1.5	2.5
Lindane	1.2	1.0	---	---
Heptachlor	0.7	1.0	---	---
1,4-Dichlorobenzene	---	2.8	---	---
N-Nitroso-N-propylamine	10	12	---	---
2,6-Dinitrotoluene	0.8	0.4	1.4	1.0
2,4-Dinitrotoluene	---	---	1.4	1.0
Diethylphthalate	8.0	6.8	3.8	4.8
4-Bromophenylphenyl ether	---	---	---	2.3
Phenanthrene	1.0	2.2	---	2.1
Anthracene	1.2	2.6	---	---
Di-N-Butylphthalate	32	19	7.3	---
Butylbenzylphthalate	10	4.0	1.4	2.0
Bis (2-ethylhexyl) phthalate	52	71	6	14
Benzo (G,H,I) perylene	17	12	0.8	---

*Screened for all extractable (semivolatile) priority organics except 2,3,7,8-tetrachlorodibenzopara-dioxin (TCCD). Compounds that were not detected in any of the samples from the four sample points are not included in the above lists.

--- Means not detected.

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TABLE C-3. PRIORITY METALS DATA*

Compound	Raw Waste-water	Primary Effluent	Unchlorinated Secondary Effluent	Chlorinated Secondary Effluent
		Concentration (mg/l)		
Antimony	**	<0.05	<0.05	<0.05
Arsenic	**	<0.05	<0.05	<0.05
Bromine	**	<0.01	<0.01	<0.01
Chromium	**	0.06	0.05	0.06
Copper	0.17	0.035	0.011	0.022
Nickel	<0.2	<0.2	<0.2	<0.2
Selenium	**	<0.1	<0.1	<0.1
Zinc	0.91	0.65	0.27	0.45
		Concentration (µg/l)		
Cadmium	3	<0.5	0.5	1
Lead	38	15	<0.5	<0.5
Mercury	<4	<4	<4	<4
Silver	3	2	2	3

*Screened for all priority metals excepot thallium; analysis of spiked thallium samples revealed a negative recovery and, thus, an interference in the procedure.

**Indicates insufficient samples to complete anlaysis.

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